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Degree for which thesis was presented — Grade pour lequel cette thèse fut présentée

PhD

Year this degree conferred — Année d'obtention de ce grade 1983	Name of Supervisor — Nom du directeur de thèse HA QUINNEY

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A COMPARISON OF THE EFFECTS OF ISOMETRIC AND ISOKINETIC TRAINING ON MUSCLE FIBRE SIZE AND STRENGTH IN WOMEN WITH RHEUMATOID ARTHRITIS

by

Ⓒ Jean Wessel

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF Doctor of Philosophy

Department of Physical Education

EDMONTON, ALBERTA
SPRING 1983

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External Examiner

Date Dec. 16, 1982

ABSTRACT

Persons with rheumatoid arthritis are known to have muscle weakness and atrophy. Results of a few investigations suggest that exercise can improve strength and increase muscle fibre size in these patients. However, no studies compared the effects of different strength training programs.

The purpose of this study was to compare the effects of isokinetic and isometric training of knee extension on the strength of quadriceps and cross-sectional area of type I and II muscle fibres of the vastus lateralis of women with rheumatoid arthritis.

Thirty-one women between the ages of 23 and 59 with stage I or II rheumatoid arthritis were randomly assigned to one of three groups. Subjects in two exercise groups attended three times weekly for seven weeks for training of their quadriceps. The isometric group performed one maximal isometric contraction at each of three angles of the knee, while the isokinetic group performed three sets of six dynamic contractions at 180°/sec. The control group underwent all the test procedures, but received no program of exercise.

Knee extension torque was tested before and after the training program at five velocities - 0°, 48°, 96°, 144°, 192°/sec - on a Cybex II isokinetic dynamometer. Pre- and post-test samples of the vastus lateralis muscle were obtained by needle biopsy, and area of fast and slow twitch fibres measured from sections prepared and stained for ATPase. Function, pain and parameters of disease activity were evaluated in all subjects before and after the experimental period. In addition, the two exercise groups graded the severity of pain experienced during each training session.

Both training groups improved in peak torque, and measures of power and work. The isometric group had its greatest changes at the slow speed or isometric contractions. The isokinetic group had improvements at faster velocities as well, although peak torque did not improve significantly at the velocities above 96°/sec.

There were no statistically significant changes in fibre size in any of the three groups, although the isokinetic group showed a trend towards greater improvement in the fast twitch fibres, and the isometric group greater changes in the slow twitch fibres.

The isometric group experienced significantly more pain during exercise sessions than the isokinetic group which also had a pre/post decrease in rating of overall pain. There were no statistically significant changes in measurements of disease activity in any of the groups over the study period. Both the control and the isokinetic groups, however, had slightly better function scores post-study.

It is concluded that the patient with rheumatoid arthritis can benefit from a strength training program with improvement in torque, work and power measurements. The results suggest a trend towards specificity of training effect for the two modes of exercise employed in the study. When choosing a method of exercise for a rheumatoid patient, the individual's pain and type of daily activity must be taken into consideration.

Further investigation with other forms and intensities of training is necessary to determine the exercise required for optimal improvement in functional activities and muscle atrophy in persons with rheumatoid arthritis.

ACKNOWLEDGEMENTS

The undertaking of this study was not possible without the support and cooperation of many people. I would like to thank my advisor, Dr. HA Quinney, who provided direction and support in the planning, execution, and presentation of the research. I greatly appreciated his continued interest and confidence in the project, and his assistance with the practical interpretation and application of the results.

To the members of my committee, Drs. P Davis, AS Russell, R Steadward, and J Vargo, thank you for providing direction and assistance in the design and implementation of the study. Drs. Davis and Russell, along with Dr. J Percy allowed their patients to be used in the study. Dr. Vargo spent many hours assisting me with statistical analysis and computer manipulation of the data.

I wish to express my very special appreciation to Dr. DC Reid for his continuing interest in the project and for spending many hours performing the muscle biopsies on the study patients. I am sure his technical skill and manner with patients were responsible for the high return of subjects for the post-test biopsies.

I would like to thank the Department of Physical Therapy for providing the facilities and equipment necessary for the training and testing of patients. In addition, the staff and faculty with their interest and concern, constantly provided moral and logistic support.

I would like to thank the Department of Anatomy for the use of their photomicrograph equipment. I also appreciate the time taken by individual faculty members to discuss technical considerations in the preparation and analysis of the muscle samples.

The staff members in the Rheumatology Department provided assistance and encouragement whenever needed. All the muscle biopsies were performed in the department and the staff often assisted in the acquisition of necessary materials. I would like to thank all the staff, but in particular Mrs. C Johnston for her technical assistance and suggestions.

The patients in the study so willingly gave of their time to attend for training and assessments. In addition, their interest in the research and its potential results was a source of continued inspiration throughout the study. I am very grateful to these special people for their committment to the project.

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I. INTRODUCTION

Rheumatoid arthritis (RA) is a common, potentially crippling disease. In addition to the problem of joint inflammation, muscle atrophy and weakness have long been recognized as common features of the disease (Paget 1873), and may contribute significantly to the decrease in function experienced by persons with this condition. Histological studies have reported pathological changes in the muscle (Haslock et al 1970, Wegelius et al 1969, Wróbleski and Nordemar 1975) as well as in the muscle spindles (Magyar et al 1975), blood vessels (Oka et al 1971, Wróbleski and Nordemar 1975, Haslock et al 1970), and nerves (Edström and Nordemar 1974, Haslock et al 1970). The inflammatory process in the muscle appears to lead to degeneration of muscle fibres (Haslock et al 1970, Wegelius et al 1969, Wróbleski and Nordemar 1975) with preferential atrophy, at least in the early stages of the disease, of the fast twitch or type II fibres (Edström and Nordemar 1974, Haslock et al 1970, Brooke and Kaplan 1972). Compared to normal subjects, persons with RA have decreases in both static and dynamic strength (Tiselius 1969, Ekblom et al 1974, Richards 1980).

Information on the role of exercise in the reversal of the muscle atrophy and weakness has been less conclusive. Three studies (Mclaughlin and Reynolds 1973, Cuddigan 1973, Luckhurst et al 1974) showed no improvement in strength following training programs which included either isometric or isotonic contractions. On the other hand, Machover and Sapechy (1966) reported a gain in strength in the isometrically trained quadriceps of persons with RA but not in the contralateral non-exercised limb. A series of Scandinavian studies (Ekblom et al 1975a & b, Nordemar et al 1976a & b). reported significant improvements in both isometric and dynamic strength of muscle groups in patients with arthritis following a physical training program which included strengthening exercises on a quadriceps table. The same training program also produced increases in size of type I and type II muscle fibres with the greater increase occurring in the latter (Nordemar et al 1976a).

One major difficulty in comparing the results of these studies and generalizing the findings to a population of RA patients is the variation of control groups used. None of the studies used a control group of individuals with RA receiving no exercise, or another experimental group of RA patients receiving an alternative but specific exercise program.

Clinically, isometric exercises are often the choice when providing a strengthening program for RA as it has been shown that repeated movement of a swollen joint can increase joint inflammation (Agudelo et al 1972), joint temperature (Hollander and Horvath 1949) and possibly the activity of enzymes destructive to the joint (Harris and McCroskery 1974). However, high intensity dynamic exercises would appear more conducive to recruitment of fast twitch fibres

(Lesmes et al 1979), the fibres that are affected the most in RA. By providing the dynamic exercise on an isokinetic dynamometer, some of the problems of isotonic exercise may be avoided. Subjects can exercise to their maximum without exceeding their pain tolerance because of the accommodating resistance of the machine (Hislop and Perrine 1967, Thistle et al 1967). With isokinetic exercise, the resistance to the muscle group is maximal throughout the range, while a maximal contraction is only obtained in a small part of the range of movement during an isotonic exercise.

The purpose of this study was to compare the effects of an isometric and an isokinetic program of exercises on the strength and muscle fibre size of the quadriceps muscle of persons with RA. A secondary objective was to compare the programs for their effect on joint pain and swelling.

A. DELIMITATIONS

The study is limited to:

1. Females aged 23 to 59 with stage I or II rheumatoid arthritis and without any other musculoskeletal or cardiovascular problems.
2. Training of knee extensors with isometric or isokinetic (180°/sec) contractions three times weekly for seven weeks.
3. Isometric training of one maximal contraction at each of three angles of the knee.
4. Isokinetic training at 180°/sec with three sets of six

repetitions through 90° range of knee motion.

5. Testing of muscle strength by means of a Cybex isokinetic dynamometer.
6. Determination of muscle fibre size and types by means of ATPase staining of a sample obtained by needle biopsy.
7. Evaluation of exercise pain by the Borg scale and an analogue pain scale.

B. DEFINITIONS

1. ISOKINETIC EXERCISE: A dynamic muscle contraction at a constant controlled speed of movement against an "accommodating resistance".
2. ISOMETRIC EXERCISE: A muscle contraction without perceivable muscle shortening or joint movement.
3. ISOTONIC CONCENTRIC EXERCISE: A muscle contraction with muscle shortening and joint movement. Traditionally, resistance is provided with a dead weight, and therefore is only maximal in a small part of the range of movement.
4. ISOTONIC ECCENTRIC EXERCISE: A muscle contraction with muscle lengthening and joint movement.
5. KNEE RANGE OF MOTION: 0° is full knee extension.
6. MUSCLE FIBRE TYPES:
    a. Type I/Slow Twitch/ST: Muscle fibres that stain very lightly for ATPase with alkaline preincubation. They have a long contraction time, are fatigue resistant, and have a long time to peak tension.

   b. Type II/Fast Twitch/FT: Muscle fibres that stain dark for ATPase with alkaline preincubation. They have a shorter contraction time, fatigue more quickly, and achieve peak tension sooner than type I fibres.

7. MVC: Maximal voluntary contraction of muscle - usually referring to a maximal isometric contraction.
8. RM: Repetitions Maximum - eg. 1 RM is the maximal weight that a person can lift only once; a 10 RM the maximal that can be lifted only 10 times.
9. STRENGTH: Maximal force that can be exerted against an immovable resistance by a single contraction (Müller 1970). In this study strength and strength measurement refer to force or torque produced by a maximal dynamic or isometric contraction.

II. REVIEW OF THE LITERATURE

A. INTRODUCTION

The review of the literature begins with a general description of rheumatoid arthritis followed by a more detailed analysis of the pathology and clinical features of this disease as related to muscle and its strength. A review of strengthening programs includes results on normal individuals, on those with pathology, and on persons with rheumatoid arthritis. Emphasis is on results of isometric and isokinetic programs. Test procedures used in this study are also discussed. They include isokinetic dynamometry, the histochemical analysis of muscle biopsies, and clinical assessment of disease activity in rheumatoid arthritis.

B. RHEUMATOID ARTHRITIS

GENERAL DESCRIPTION

Rheumatoid arthritis is a chronic disease usually involving inflammation of synovial joints combined with a variety of non-articular manifestations (Rodnan 1973). The clinical and laboratory criteria required for the diagnosis of classical or definite rheumatoid arthritis are listed in Appendix A (Rodnan 1973).

The course of the disease as described in the "Primer of Rheumatic Diseases" (Rodnan 1973), is quite variable and often characterized by a series of remissions and exacerbations. If inflammation of the joint persists, the synovial lining becomes thickened and can form a "pannus" which will eventually erode joint cartilage and the underlying bone. Tendons, ligaments and the joint capsule are often stretched and weakened by the inflammation. The final result can be joint instability, subluxation and deformity. The disease process may also lead to adhesion formation and subsequent bony ankylosis of the joints.

The cause of the disease and the inflammation are unknown. However, the inflammatory process is similar to that resulting from other diseases or injury. In the joint, the inflamed synovium is characterized by an increased number of lining cells, increased blood supply, and infiltration of inflammatory cells (polymorphonuclear leucocytes, plasma cells, lymphocytes). The synovial fluid also has a greater number of leucocytes, as well as being greater in volume and lower in viscosity.

MUSCLE WEAKNESS AND ATROPHY

As early as 1873, Paget noted accompanying muscle wasting in almost all acute joint inflammations. This wasting was more rapid and extensive than what would be expected from disuse alone. Since that time, the characteristics and pathology of muscle weakness in rheumatoid arthritis have been well described.

Strength Measurements

Tiselius (1969) measured the isometric strength of 12 muscle groups of 34 males and females with classical or definite rheumatoid arthritis. Anatomical stage of the disease of the subjects was I to III (see Appendix B for description of anatomical stages). Table 2.1 illustrates the mean of the measurements of the rheumatoid patients expressed as a percentage of mean normal values from the studies of Asmussen and Heebøll-Nielson (cited in Tiselius 1969) and Bäcklund and Nordgren (1968).

The total muscle index (TMI) - the mean of all the values in table 2.1 - was 69.1%. Tiselius found a negative correlation between the muscle index and measurements of disease activity. The latter included erythrocyte sedimentation rate (ESR), orosomucoid via acid or gel electrophoresis and α2-globulin. In another study, the author tested 18 rheumatoid subjects for quadriceps strength and heat count of the knee joint by infrared thermography on two occasions approximately two months apart (Tiselius 1969). Changes in strength correlated to changes in joint heat (r=-.84). However, when Tiselius aspirated the knee joint(s) of 10 patients, there was no significant change in quadriceps strength.

Ekblom et al(1974) studied the physical performance of females with rheumatoid arthritis, and included in their tests isometric measurements of elbow flexion and knee flexion and extension at 90 degrees, and dynamic measurements of knee extension between 30° and 0° on a "specially constructed" quadriceps table. Table 2.2 shows their results compared to a normal group.

TABLE 2.1

ISOMETRIC STRENGTH OF PERSONS WITH RHEUMATOID ARTHRITIS

	Percent of Normal Values	
MUSCLE TEST	RIGHT	LEFT
Upper Limb		
gripping strength	52.0	54.2
pinching	52.6	54.6
pronation	63.8	64.6
supination	59.2	61.7
elbow extension	87.2	91.4
elbow flexion	71.0	72.5
horizontal pull	61.4	59.9
horizontal push	74.5	79.0
Lower Limb		
knee extension	77.5	82.4
knee flexion	81.3	80.6
ankle plantarflexion	60.0	58.6
ankle dorsiflexion	79.0	79.2

Richards (1980) recorded knee flexion and extension torque in rheumatoid arthritic females between the ages of 22 and 57. The peak torques at 30°, 90° and 180°/sec were less than those recorded for normal subjects. The reduction in mean peak extension torque was 33% and in peak flexion torque 43%. This relationship was similar at the three speeds. However, at a knee angle of 45°, the ratio of the torques at 30° and 180°/sec was greater for the rheumatoid

TABLE 2.2

MAXIMAL ISOMETRIC AND DYNAMIC STRENGTH IN NORMAL AND RHEUMATOID FEMALES

ISOMETRIC STRENGTH	RA GROUP	NORMAL GROUP	DIFFERENCE
(Newtons)	Mean±SD	Mean±SD	% OF NORMAL
Elbow Flexion			
best arm	87.1±16.0	140.3±07.8	37.9
worst arm	75.3±13.6	131.5±03.9	42.7
Knee Flexion			
best leg	79.1±06.0	118.7±06.9	33.4
worst leg	64.3±05.6	115.8±05.9	44.5
Knee Extension			
best leg	139.5±07.8	219.7±14.7	36.5
worst leg	105.7±09.3	208.0±16.7	49.2
DYNAMIC STRENGTH			
(Joules)			
Knee Extension			
best leg	16.1±01.2	24.8±01.8	35.2
worst leg	09.7±01.0	20.2±01.4	52.0

group than the normal group. This indicates that the relative reduction of torque with speed is greater in persons with RA. At all speeds, the torque-angle relationships were similar in normal and RA subjects though torque values were lower for the latter.

Richards reported significant correlations between torque and age, and torque and weight in the normal subjects but not in those with rheumatoid arthritis. She also found that all torque and work (area of the torque curve) measurements were highly correlated.

Rothstein et al (1981) measured isokinetic torque and power of knee extension in 20 patients with rheumatic diseases (11 RA) and receiving treatment with steroids. There were no significant differences in torque values between the patients and 11 age and activity matched control (normal) subjects. However, the patients had lower power at the four speeds measured eg: at 120°/sec the patient group had a mean value of 32.29 Nm radians/sec and the control group a mean value of 49.34 Nm radians/sec. There was also a difference in the slope of the power-velocity regression line (patients 2.15, normal subjects .355). The results, like those of Richards (1980), suggest that rheumatoid patients have decreased muscle function particularly at the higher velocities.

The lower strength values in RA could be related to a number of pathological changes of the neuromuscular and skeletal systems, changes that have been well documented in this disease.

Pain

Pain, particularly of joints, but also of muscle, is a common feature of the disease and could certainly inhibit maximal muscle contraction. Machover and Sapechy (1966) reported that several of their subjects experienced pain during 6-second maximal isometric contractions. Ekblom et al (1975a & b) also noted pain complaints in some of their RA subjects during strength and function tests. However, severity of pain and its correlation with strength measurements were not reported in any of the three studies.

Tiselius (1969) noted that the lower strength recorded in his study was not accompanied by pain. Ekblom et al (1974) also concluded from questioning their subjects, that local pain was not the only factor affecting physical performance. Specifically, they found low strength measurements even in subjects with no local muscle or joint pain.

Joint Swelling

Joint swelling is another possible cause for decreased strength. DeAndrade et al (1965) injected knees with fluid to note its affect on the ability of the subject to extend the knee the final 10 degrees. They noted that in the majority of rheumatoid knees, pain of the knee occurred before the inability to lift the leg. This was in contrast to the normal subjects who did not experience pain at the onset of muscle weakness. Electromyographic (EMG) recordings from the vastus lateralis of one rheumatoid subject showed a decrease in amplitude and number of action potentials with inability to extend the knee. The authors viewed this as evidence of muscle weakness as a cause for inhibition of extension rather than mechanical inhibition due to joint distension. They believed the mechanism of muscle inhibition is through stimulation of joint receptors as a result of joint distension. Review by these authors of other literature available at the time also suggested a simultaneous facilitation of the flexors.

A more recent study (Stratford 1982) supports the theory of DeAndrade et al. The ratio of EMG of the quadriceps at 0° and 30° of knee flexion was less in effused knees than normal knees, again indicating a decreased recruitment of muscle fibres as the knee approaches full extension.

As previously indicated, Tiselius (1969) found no improvement in strength measurements of the knee at 90° when the joint was aspirated. These results would tend to contradict those of deAndrade et al (1965). However, measurement at a different knee angle may explain conflicting results. Data on one subject in the study of Tiselius (1969), showed that the intra-articular pressure recorded in full knee extension with quadriceps contraction was 318 mm Hg compared to only 57 mm Hg with active muscle contraction at 90°. The volumes of fluid either aspirated or injected were similar in the two studies. It would appear that the stretching of the capsule and the resulting inhibition would be less at the 90° angle.

Muscle Pathology

An inflammatory process similar to that described for the joints has been found in the muscles of patients with rheumatoid arthritis. The inflammatory cells - lymphocytes, plasma cells, macrophages and occasional eosinophils - appear in groups or nodules which are distributed throughout the entire muscle (Curtis and Pollard 1940, Freund 1945, Freund et al 1945, Steiner et al 1946, Wegelius et al 1969, Haslock et al 1970). They are located at the periphery of muscle fibres near the endomysium or perimysium (Moritz 1963) and around muscle capillaries (Haslock et al 1970, Wróbleski and Nordemar 1975).

Although the inflammatory process of the muscle is again not specific to the disease, Freund et al (1945) and Steiner et al (1946) concluded that the nodular formation of the infiltrating cells and the presence of hypertrophic collagenous fibres without increase of reticulin fibres in the nodules were unique to rheumatoid arthritis. Others pointed out that a greater number of plasma cells distinguishes the rheumatoid myositis from polymyositis (Haslock et al 1970), or that the frequency of occurrence of muscle inflammation is greater in RA than in many other diseases (Moritz 1963, Wegelius et al 1969). The muscle pathology has been found in muscles remote from affected joints and in persons with clinically inactive disease (Freund et al 1945, Steiner and Chason 1948).

The myositis leads to muscle fibre changes that have been reported by several authors. An irregular pattern of muscle atrophy occurs with normal sized fibres adjacent to atrophied ones (Freund et al 1945, Wegelius et al 1969, Haslock et al 1970).

Most authors (Brooke and Kaplan 1972, Haslock et al 1970, Edström and Nordemar 1974, Dubowitz and Brooke 1973) have reported greater atrophy of the type II fibres in the earlier stages of the disease with increasing involvement of the type I fibres in the later stages. Dubowitz and Brooke (1973) reported on four subjects in stage III of the disease who had selective atrophy of type I fibres. Their stage IV patients, however, had atrophy of both fast and slow twitch fibres.

Haslock et al (1970) attributed the greater involvement of the type II fibres in the early stages of the disease to a greater susceptibility of these fibres to the influence of cachexia which they felt was due to interference by the disease process with muscle cell nutrition. Their conclusions are supported by the finding of type II atrophy in other diseases that are characterized by muscle inflammation (Brooke and Kaplan 1972, Dubowitz and Brooke 1973). However, a change in nerve and muscle stimulation may also play a role as suggested by the type II atrophy reported in conditions with tonic spasticity (Edström 1970a & 1973, Edström et al 1972) and following dennervation (Engel 1970).

The type I atrophy that is seen later in RA may be related to disuse. Greater atrophy of this type of fibre has been seen following immobilization although both types of fibre are involved (Tomanek and Lund 1974, Sargeant et al 1977, Patel et al 1969). A decrease in size of slow twitch fibres has also been observed in ligament injury (Edström 1970b, Eriksson 1976), a condition which might resemble the joint dysfunction in stage III RA.

Edström and Nordemar (1974) quantified the size of the muscle fibres in the vastus lateralis of rheumatoid males and females by determining the frequency of fibres with cross-sectional areas less than 1500 u^2. Fifty percent of type II fibres and only 8% of type I fibres had areas below this value. Nordemar et al (1976b) reported pre-training muscle areas in RA patients of 3290 u^2 and 2890 u^2 for ST and FT fibres respectively. Corresponding values for the vastus lateralis of normal male subjects are 4000-5000 u^2 for the type I fibres and 5000-6000 for the type II fibres. For women, the values are slightly less, with the FT fibres (2500-3500 u^2) being smaller than the ST (3500-4000 u^2). (Edström and Ekblom 1972, Nygaard 1981, Saltin et al 1977)

Muscle atrophy in RA includes loss of peripheral myofibrils, and decrease in length of sarcomeres and loss of striation in the remaining myofibrils (Freund et al 1945, Wróbleski and Nordemar 1975). Intermyofibrillar mitochondria have a normal appearance but are less frequent or absent, whereas sarcolemmal mitochondria can be increased in number (Wróbleski and Nordemar 1975). Nuclei generally maintain their normal position below the sarcolemma, although internal movement of the nuclei has been reported, probably in the more severe cases of RA (Haslock et al 1970, Brooke and Kaplan 1972). When the size of the muscle fibre is greatly reduced, its nuclei form long chains or clumps (Haslock et al 1970).

The plasma membrane of the muscle cell remains intact, but its basement membrane is thickened (Wróbleski and Nordemar 1975). The area between the sarcolemma and the remaining myofibrils is not usually replaced by fibrosis (Haslock et al 1970). However, Haslock et al (1970) reported two cases of "chronic myopathy". There were gross changes in the muscle fibres with fibrosis and replacement by adipose tissue, splitting of fibres, and in some cases, appearance of vacuoles both peripherally and centrally.

Other infiltrates that have been found in the rheumatoid muscle include lipofuscin granules and satellite cells (Wróbleski and Nordemar 1975). The presence of the former which are residual bodies of lysomes would suggest a destructive process resulting from the release of lysozymes. Satellite cells are regarded as a sign of regeneration (Wróbleski and Nordemar 1975).

Nordemar et al (1974) analysed RA muscle for adenosine triphosphate (ATP), adenosine diphosphate (ADP), adenosine monophosphate (AMP), creatine phosphate (CP), creatine and several intermediates of the glycolytic chain. ATP was the only compound found in lower concentration in RA than in either normal subjects or persons with other arthritic problems. The ratio of ATP to ADP and AMP was similar in the three groups. Low ATP concentrations have been reported in normal individuals at fatigue and have been related to decreases in muscle force at any velocity (Jørgensen and Emmerich 1976).

Wróbleski et al (1978) found that the decrease in ATP in rheumatoid muscle was not associated with a lower content of total phosphorus. The authors also reported significantly lower levels of sulfur in the type II fibres of rheumatoid subjects compared to healthy controls. This could be related to the greater atrophy of these fibres with resultant loss of some sulfur containing proteins. In two of their subjects with marked atrophy of fibres, sulfur content was also less.

Changes in Electromyography

Various characteristics of the EMG of the rheumatoid muscle have been compared with that of normal subjects. Some of the more common findings are decreases in duration and amplitude of the motor unit action potential and more frequent occurrence of multiphasic potentials. These changes are probably due to the inflammatory process in the muscle, and are generally more common in the small muscles of the hand than in more proximal muscles. (Petersén 1955, Graudal and Hvid 1959, Moritz 1963, Edström and Nordemar 1974).

Spontaneous EMG activity resembling fibrillation potentials has also been found in RA muscles, again more frequently in the hand (Graudal and Hvid 1959, Moritz 1963). It was concluded by Moritz (1963) that this EMG activity at rest was really prolonged insertion activity and was due to an increased irritability of the muscle as opposed to degeneration of the lower motor neuron.

Moritz (1963) found a reduced interference pattern of EMG at MVC in a number of different muscle groups of RA subjects. Richards (1980) reported lower values of IEMG for knee extensors and flexors during maximal isokinetic contraction of these muscles at both 30°/sec and 180°/sec. The difference in IEMG of the knee extensors between normal and RA subjects was greater as the knee approached full extension. As the reductions in EMG were accompanied by decreases in torque values, the findings suggest that low strength recording in RA may be due in whole or in part to a decrease in the number of muscle fibres that are recruited during a maximal contraction.

Nerve Involvement

Nodular inflammation similar to that described for muscle has been found in the nerves of rheumatoid patients (Haslock et al 1970, Freund et al 1945). Demyelination and subterminal branching of axons have been observed (Haslock et al 1970). The latter suggests the development of collateral innervation following dennervation of the muscle. In the majority of rheumatoid patients, however, the neurological involvement does not contribute significantly to muscle weakness. Sensory neuropathy is more prevalent than motor, and muscle pathology and decreased strength have often been noted in the absence of neural changes (Edström and Nordemar 1974, Haslock et al 1970).

Changes in Circulation

Decreased circulation has been cited as a possible cause of pathology in nerves, muscles and muscle spindles of persons with RA (Haslock et al 1970, Magyar et al 1973, Wróbleski and Nordemar 1975). Oka et al (1973) found that muscle blood flow was indeed greatly reduced in RA both at rest and after muscular ischemia. Others have reported changes in capillaries including thickening of the basement membrane and the endothelial cells. The latter leads to a decrease in size of the lumen (Wróbleski and Nordemar 1975, Magyar et al 1973). Capillary pathology is probably the most common cause of neuropathy in RA patients due to the involvement of the vaso nervorum (Rodnan 1973).

Muscle Spindle Changes

Magyar et al (1973) reported pathological changes in the muscle spindles of all 10 rheumatoid subjects in their study. The changes included thickening of the capsule, often accompanied with narrowing of the periaxial space. Degeneration of both types of intrafusal muscle fibres was noted, and their nuclei were markedly changed in size, appearance and arrangement. Nerve supply appeared to be greatly diminished or absent. The authors suggested that the changes in the spindle are due to vasculitis affecting the circulation to either the intrafusal fibres or their nerve supply.

Drug-Induced Changes in the Neuromuscular System

Patients on systemic corticosteroids can develop a myopathy. Haslock et al (1970) noted an increased number of intra-cellular lipid deposits in the muscles of such persons. The changes were particularly evident in the slow twitch fibres. Wróbleski and Nordemar (1975) reported that steroids and chloroquine can give rise to myopathy.

Morgan et al (1981) described a patient with RA who developed myositis following treatment with d-penicillamine. There was a large degree of fibre necrosis and elevation of creatine phosphokinase (CPK).

C. CHARACTERISTICS OF MUSCLE FUNCTION OF THE KNEE EXTENSORS

Force or torque recordings of knee extension are affected by both the angle of the knee and the velocity of the movement. At a given angle, the force the quadriceps can produce is dependent on the length-tension relationship of muscle and the moment arm of the muscle. The length of the latter changes considerably because of changes in the position of the centre of rotation of the knee joint due to the combination of rolling and gliding movements of the femur on the tibia during flexion (Smidt 1973).

The force-angle relationship during an isometric contraction produces a curve like the one depicted in figure 2.1 (Lindahl et al 1969, Murray et al 1977, Scudder 1980, Williams and Stutzman 1959). The difference between the 30° and 60° angles is generally reported as greater than the change from 60° to 90° (Lindahl et al 1969, Williams and Stutzman 1959, Clarke and Bailey 1950). In fact the angle of greatest torque production is not the same in all subjects, and may occur anywhere between 45° and 90° (Murray et al 1977, Williams and Stutzman 1959).

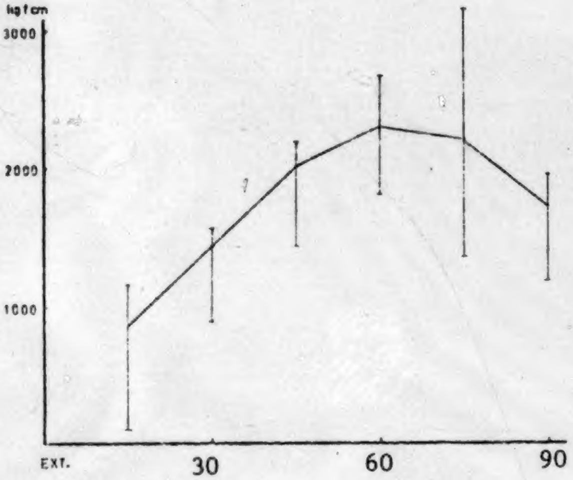
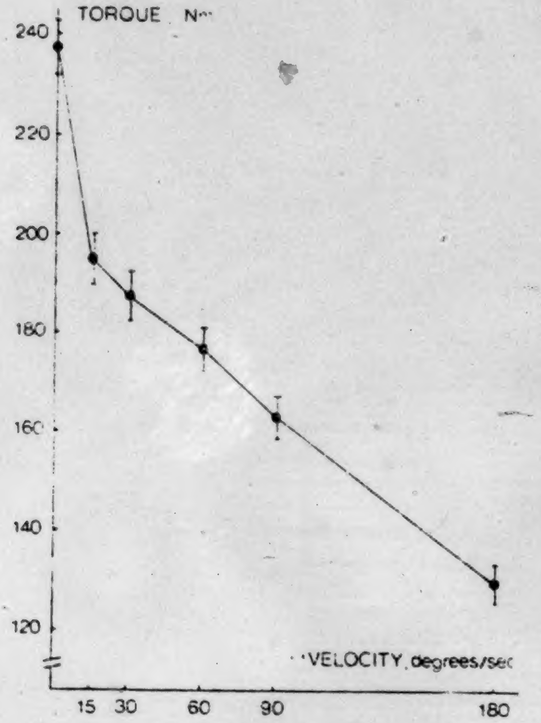


Figure 2.1: Force-angle relationship of the knee extensors. (from: Lindahl et al 1969)

Force-velocity curves of isolated muscle are hyperbolic in nature with force decreasing as velocity increases (Thorstensson et al 1976a). In vivo studies on the human knee extensors also show declining force or torque with faster velocities. However, the shape of the curve has not been the same in all studies. Thorstensson et al (1976a), Scudder (1980) and Parker et al (1980) reported curves closer to the shape of the force-velocity relationship of isolated muscle (figure 2.2A). Others have found the curve to be flatter at the lower speeds (Perrine and Edgerton 1978, Gregor et al 1979, Wickiewicz et al 1982) (figure 2.2B).

Isometric and dynamic torque measurements of the knee extensors are highly correlated (Johnson 1982, Richards 1980). As well both have been positively correlated to

A



from: Thorstensson
et al (1976a)

B

from: Perrine and
Edgerton (1978)

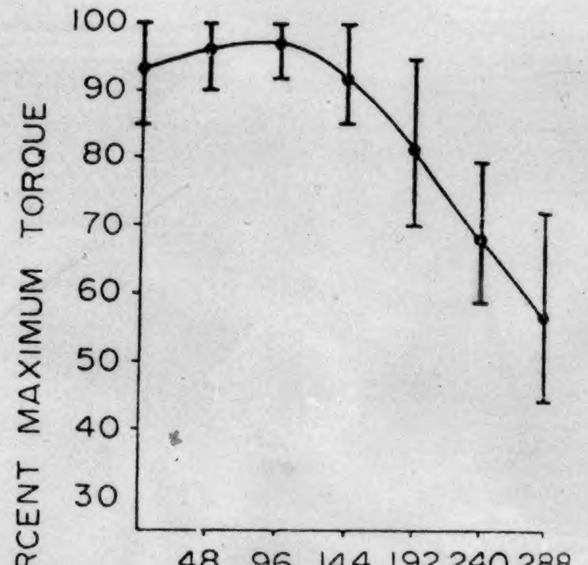


Figure 2.2: Torque-velocity relationships of the knee extensors

height and weight and negatively correlated with age (Richards 1980, Johnson 1982).

Normal values for peak extension torque of the knee in women range between 100 and 130 Nm (Richards 1980, Johnson 1982, Moffroid et al 1969, Goslin and Charteris 1979) at a speed of approximately 30°/sec. The torque decreased to a value of 81 Nm at 180°/sec in Richards' (1980) study, and increased to 154 Nm during an isometric contraction in the younger group of women in the study of Johnson (1982).

D. TESTING WITH AN ISOKINETIC DYNAMOMETER

The isokinetic dynamometer and the concept of isokinetic exercise were introduced in the literature in 1967 (Hislop and Perrine 1967, Thistle et al 1967). A special apparatus with a braking mechanism is required to control the speed of movement (Hislop and Perrine 1967, Thistle et al 1967, Perrine 1968). As more effort is exerted against the input shaft of the isokinetic device, the additional energy cannot be dissipated by acceleration of movement, and is instead converted to resisting force (Hislop and Perrine 1967). The torque produced at the input shaft of the dynamometer is detected by an internal load cell (Perrine 1968) or a potentiometer sensitive to pressure (Richards 1980) and displayed on a suitable recorder. An isokinetic dynamometer, such as the Cybex II[1], therefore, provides a means of studying the relationship of speed of movement to other properties of in vivo human muscle, such as force, power, and fatiguability. Angle specific characteristics can be determined with the use of a microswitch attached to the input shaft to mark a specific angle or a potentiometer for measuring angular movement of the input shaft.

CALIBRATION OF EQUIPMENT

Some authors have reported calibrating torque readings of the Cybex on a daily basis (Lesmes et al 1978), while the results of Richards suggest that torque measurements do not vary significantly over several months (Richards 1980). The calibration can be performed by applying known weights to the arm of the dynamometer when it is in a horizontal position at a speed of 0°/sec. The output on the recorder can then be adjusted to correspond to the torque calculated by multiplying the length of the lever arm times the weight applied (Moffroid et al 1969, Richards 1980, Thorstensson 1976, Knapik and Ramos 1980). Moffroid et al (1969) found that after calibrating with one weight, there was a linear relationship between applied weights of different sizes and torque recording. Using ten test-retest sessions with seven loads, they calculated a coefficient of reliability of r=0.995. Comparing predicted to obtained torque at various angles produced a coefficient of validity of r=0.999.

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[1] Cybex Division, Lumex Corporation, Bay Shore, New York 11706

Others (Magee 1980, Lesmes et al 1978) have calibrated torque by allowing the weighted lever arm to pass through a range of motion at a set speed. Mawdsley and Knapik (1982) found a test-retest reliability coefficient of 0.993 using two weights and a speed of 30°/sec, the velocity recommended for calibration by the manufacturers of the Cybex (see Appendix C).

Lesmes et al (1978) calibrated velocity of the machine daily by counting the number of complete revolutions of the input shaft in one minute. They calculated total methodological error to be ±4%. Richards (1980) checked velocity periodically by measuring the slope of the recording from the angle potentiometer of the input shaft.

An additional piece of equipment that may be supplied with the Cybex system is a work integrator. Its calibration is described in Appendix C.

SUBJECT PREPARATION

Richards (1980) reviewed the importance of body stabilization and position in strength measurement. Others (Magee 1980, Thorstensson 1976) have described the standardization of these when using the Cybex. Most authors have indicated that the axis of rotation of the input shaft should be aligned with that of the joint being examined (Magee 1980, Thorstensson 1976, Cybex System Handbook, Moffroid and Kusiak 1975, Osternig et al 1977, Cooper et al 1981). However, Richards (1980) is one of the few who described the anatomical landmarks for determining the location of the centre of rotation of the joint she tested.

Although many papers have indicated that subjects are given a period of familiarization with the testing equipment, fewer have been specific about the nature of the instructions or the number of "practice" contractions (Magee 1980, Richards 1980, Cybex System Handbook). The study of Johnson and Siegel (1978) indicated that in the measurement of isokinetic "force" of the knee extensors, three submaximal trials followed by three maximal warm-up efforts are necessary to establish stability of measurements. However, Mawdsley and Knapik (1982) used no warm-up period and found no differences in maximal peak torque over three sessions each separated by two weeks. Within each session the order of magnitude of the peak torque of six trials varied, decreasing in value with successive trials in session one and increasing in sessions two and three. A common practice has been three maximal contractions for each test (Richards 1980, Cooper et al 1981, Campbell and Glenn 1982). For isokinetic contractions, the subjects are usually told to move or kick as fast and/or as hard as possible (Cybex System Handbook, Richards 1980, Mawdsley and Knapik 1982).

PRODUCTION OF TORQUE CURVES

The torque is produced by the subject exerting force (usually maximal) against the lever arm of the isokinetic dynamometer throughout a range of motion at a specific speed (Moffroid et 1969, Richards 1980, Thorstensson 1976, Moffroid and Kusiak 1975). This is often done in response to a specific and constant action command (Moffroid and Whipple 1970, Richards 1980, Mawdsley and Knapik 1982).

Several authors have reported both a time lag and initial oscillations in the torque curve produced by this method at higher speeds (Richards 1980, Osternig 1975, Thorstensson 1976, Perrine and Edgerton 1978. Osternig (1975) dealt with this problem by having subjects start their muscle contraction at a joint angle 20 degrees before the beginning of the range where torque was to be measured. Perrine and Edgerton (1978) utilized another method of force production at speeds below 144°/second. Subjects were asked to extend their knees from 90° to 0° (full extension), aiming to reach maximal effort by the time they reached the 30° position. By recording the torque later in the curve, they eliminated the problems described above for fast speeds, and allowed for measurement of torque at a constant muscle length and moment arm. In addition, the method of force production at slower speeds reduced the time that the muscle was contracting maximally and thus prevented a reduction in torque due to fatigue. This method necessitates the use of a microswitch or potentiometer to record the angle at which torque is to be measured.

MEASUREMENTS FROM TORQUE CURVE

Torque

The most common measurement made from the torque curve is the peak torque, ie; the highest point on the torque curve regardless of its position in the range of motion (Moffroid and Whipple 1970, Lesmes et al 1978, Richards 1980, Knapik and Ramos 1980, Molnar and Alexander 1973 & 1974). Torque has also been measured at various angles on the curve (Moffroid and Whipple 1970, Richards 1980, Osternig 1975, Thorstensson et al 1976a). Often, the best result of three efforts has been the one used for analysis (Molnar and Alexander 1973, MacDougall et al 1980a). However, an average value of all trials (Richards 1980) or of a select number of trials, eg, the mean of the two best of three tries (Cooper et al 1981) have also been used.

Torque can be presented in absolute values such as foot-pounds (ft-lbs) or Newton-meters (Nm) (Moffroid and Whipple 1970, Lesmes et al 1978, Moffroid et al 1969, Osternig 1975, MacDougall et al 1977) or expressed as a percentage of the isometric (Moffroid et al 1969, Osternig 1975, Perrine and Edgerton 1978) or a slow speed (Coyle et al 1979) torque. Osternig (1975) pointed out that the weight of the leg may have a greater negative effect on isometric torque outputs than on torque production in an isokinetic contraction particularly at higher speeds. Therefore, he suggested presenting torque in absolute terms rather than in relation to isometric values.

Richards (1980) corrected all her torque readings by adding the weight of the limb if the movement was against gravity and subtracting it if the movement was with gravity. Weight of the leg was determined throughout the range by recording the torque produced when the leg and the attached lever arm of the dynamometer were allowed to passively fall through range at a very slow speed. However, in view of the comments of Osternig (1975), this method may not add to the accuracy of analysing force of muscle contraction.

Several authors (Moffroid et al 1969, Osternig 1975) have reported a shift in the position of the peak torque to the right as velocity of movement increases. Moffroid et al (1969) suggested that at the higher speeds the optimal mechanical position of the joint is passed before the maximal muscle tension can be reached. Thus there can be difficulty in separating (and controlling) the contributions of joint angle and speed to the production of the torque. By measuring the torque at a position later in the range, Perrine and Edgerton (1978) felt they eliminated this problem.

Torque measurements have also been expressed in terms of body weight (Richards 1980, Gregor et al 1979, Larsson et al 1979).

Work and Power

Work is force times distance (Moffroid and Kusiak 1975). In angular motion, work would be force times distance moved along the circumference of a circle. For every degree of movement, the distance would be: 2pi x radius x $360^{\circ -1}$. Since torque already includes force times radius (length of dynamometer lever arm), isokinetic work can be measured by: torque x 2pi x angular displacement x $360^{\circ -1}$ (Cybex System Handbook). Moffroid and Kusiak (1975) have stated that this is equal to the area under the torque curve where the ordinate equals torque and the abscissa equals angular displacement. They calculated the work output for a square on the recording paper with known area and used this to determine the work from the torque curve. More recently, the area under the torque curve has been calculated by a digital work integrator (Lesmes et al 1978, Cybex System Handbook).

Power, which is the rate of doing work, can then be calculated by dividing the work by the time taken to produce the torque curve. It is usually expressed as watts (joules/second). Cooper et al (1981) erroneously expressed power at 180°/sec as torque x pi.

Other investigators (Perrine and Edgerton 1978, Coyle et al 1979, Gregor et al 1979) used what Moffroid and Kusiak (1975) called peak power. This is calculated by dividing the peak torque of the curve by the duration of the contraction. Thus, peak torque is substituted for work. This will not produce the same value as the power derived from the curve area (Moffroid and Kusiak 1975), but the finding of high correlations between peak torque and work appear to justify this substitution (Nilsson et al 1977, Moffroid and Kusiak 1975).

Perrine and Edgerton (1978) also used torque, but at a specific angle, to calculate power: power = torque x velocity x 2pi x $360^{\circ -1}$. Moffroid and Kusiak (1975) supported the use of torque at any angle to calculate power provided the effort is maximal at the angle measured. They did not, however, agree with the term "instantaneous power" used by Perrine and Edgerton (1978) to describe their power measurement.

Instead, Moffroid and Kusiak (1975) suggested that instantaneous power refers to the power produced between the initiation of contraction and the attainment of peak torque. In other words, instantaneous power is peak torque divided by the time taken to reach peak torque. As mentioned earlier, location of peak torque on the torque curve is dependent on both joint angle and speed of movement. Thus the meaning of this measurement may be questionable.

Perrine (1968) suggested that contractile power - the ability to develop force in a specified period of time - is more closely related to muscle function. This can be measured by using isokinetic contractions and determining the time required to reach a specific torque or the amount of torque attained in a particular time period. However, both these measurements will have the problems discussed for instantaneous power. To eliminate these, Moffroid and Kusiak (1975) measured the time required to attain a particular torque output during an isometric contraction. Richards (personal communication) indicated that the frequency response of the isokinetic dynamometer during isometric contractions may not be adequate for such a measurement. This concept also appears to be accepted by Murray et al (1977) who made extensive alterations to the Cybex before examining the time course of torque production during isometric contractions.

Measurements of Endurance

A number of terms have been used to denote ability or inability to maintain a certain work or power output on the Cybex - anaerobic power (Lesmes et al 1978, Costill et al 1979), mean power output (Costill et al 1979), fatigue index (Thorstensson 1976, Thorstensson and Karlsson 1976), and muscular endurance (Moffroid and Whipple 1970). In general, the procedure involves having the subject perform repetitive maximal contractions at a specific speed for a set time, and measuring average power or work, or the change in these parameters with time.

Many investigators have used the method introduced by Thorstensson (Thorstensson 1976, Thorstensson and Karlsson 1976, Nilsson et al 1977, Komi and Tesch 1979, Tesch 1980). Subjects exercised the knee extensors maximally at 180°/sec until 50 contractions had been completed. Knee flexion was passive and lasted approximately 0.7 seconds. The contraction phase of the quadriceps took 0.5 seconds. The peak torque of the last three contractions was averaged and expressed as a percentage of the average torque from the first three contractions. The coefficient of variance (CV) for this measure was 3.2%.

Others (Moffroid and Whipple 1970, Lesmes et al 1978, Costill et al 1979) asked their subjects to alternately contract agonists and antagonists. Costill et al (1979) and Lesmes et al (1978) worked their subjects at 180°/sec for 60 seconds and summed the work for each 10 second period. Costill et al (1979) expressed the results as a decline in mean power with time. Lesmes et al (1978) charted accumulative work output over time.

The manufacturer of Cybex suggests measuring "power endurance" by determining the time taken for the torque to decrease to 50% of its initial value (Cybex Joint Testing 1980). Contractions are performed reciprocally at 180°/sec.

RELIABILITY OF TEST PROCEDURES

Thorstensson (1976) determined the test-retest reliability when recording and measuring torque curves of subjects on an isokinetic dynamometer. The test situations included consecutive attempts in the same session, random order of velocities, and testing on two different days. The CV was greatest for testing on different days (13.7%) and approximately the same for the other two situations (8.4% and 8.5% respectively) when the torque curve was analysed at seven different angles for each of six velocities. The CV for the production of peak torque did not exceed 6.5%. Thorstensson (1976) also noted no effects of fatigue following a battery of 22 maximal contractions with rest intervals of 30-45 seconds.

When isokinetic testing was used on normal subjects and patients with chondromalacia and knee arthrosis, Nordesjö and Nordgren (1978) calculated a CV of only 5%.

Reliability of measurements with the Cybex has also been determined for subjects with RA. Deusinger et al (1979) found significant ($p \leq .05$) test-retest correlation coefficients for peak torque, instantaneous peak power, and average power of the knee extensors of persons with this disease. The test-retest correlations were not significant for the knee flexors or for time to peak torque for the knee extensors.

E. TECHNIQUES FOR IDENTIFICATION AND ANALYSIS OF MUSCLE FIBRE TYPES

HISTOCHEMICAL STAINING

Many different histochemical stains and combinations of stains have been used to classify types of muscle fibres. Some authors indicate that ATPase should be used with oxidative and glycolytic stains to differentiate types and subtypes (Dekleva and Širca 1978). However, others support the use of ATPase stain alone (Houston 1978, Brooke and Kaiser 1970). Schmalbruch and Kamieniecka (1975) reported a

98% reliability with this method of classifying cat and rat muscle into two distinct fibre types. In human muscle, the ATPase stain with preincubation at pH 9.4 is the one most likely to differentiate two, and only two types of fibres, and is the stain least altered by pathology (Engel 1974, Brooke and Kaiser 1970). Meijer and Elias (1976) compared the ATPase stain with other biochemical characteristics of human muscle and found that differentiation by ATPase generally divided the fibres into those with aerobic or anaerobic properties. The intensity of the ATPase stain also has been correlated with ATPase activity (Taylor et al 1974).

MEASUREMENT OF FIBRE AREA

Gunn (1976) established in animal muscle that there was no difference in the area of fibres of frozen or unfrozen sections. Frozen sections are used to facilitate fixing and cutting of the muscle samples.

Dubowitz and Brooke (1973) measured the least diameter of the muscle fibres as they felt that measurement of the entire area of the fibre would lead to an overestimation of its size if the cut of the section deviated at all from an exact cross-section. They employed this method to measure fibre size in many pathological conditions including RA.

Thomas and Etheridge (1982) found significant correlations between fibre area determined by planimetry and that determined from the least diameter method, although values were higher for fibre area determined by planimetry. They also found no difference in the mean area calculated from 20 fibres or 50 fibres. Others (Hooper and Hanrahan 1975, Schantz et al 1981) have supported the determination of fibre size from only a small number of fibres.

Thomas and Etheridge (1982) calculated the reliability of measurement of fibre area from a needle biopsy using the least diameter technique on twenty fibres to be r=0.85.

F. EVALUATION OF PATIENT OUTCOME IN RHEUMATOID ARTHRITIS

Disease activity in rheumatoid arthritis has been evaluated clinically for several years by a number of standard techniques. These include duration of morning stiffness, time till fatigue, number of tender and swollen joints, grip strength and time to walk 50 feet. The methods are described in detail by the American Rheumatism Association (1965). They have been used individually to evaluate RA or combined to produce a single score of disease activity (Lansbury 1958, Mallya and Mace 1981). Lansbury's systemic index has been used extensively to monitor patients' response to therapy in clinical trials and correlated highly with a detailed laboratory index of disease activity (Haataja 1975).

Hansen et al (1979) found the least inter-observer differences when measuring joint pain on passive movement, grip strength, and patient well being measured on a visual analogue scale. More inter-observer variation occurred with recording of joint swelling, and pain on pressure of joints. However, the reliability of all measures increases when only a single assessor is involved (Lee et al 1974, Hansen et al 1979, Lansbury et al 1962).

The evaluation of pain in rheumatoid arthritis in clinical studies is often performed by means of a visual analogue scale (Berry and Huskisson 1972). Scott and Huskisson (1976) assessed the use of a number of variations of an analogue scale to grade pain in 100 patients with painful conditions and found the most reliable results were with a horizontal scale with word, rather than number, descriptions of severity.

The number/word scale of Borg (1977) is used extensively for ratings of perceived exertion during exercise, and has been used successively in the same manner for patients with rheumatoid arthritis (Ekblom et al 1974, 1975a & b). More recently, the scale proved reliable in the evaluation of ischemic pain during walking (Eklund 1977).

Melzack (1975) developed a pain scale where word descriptors were converted into a quantitative measure that could be treated statistically. It was used on a number of patients with pain syndromes including those with arthritis and shown to be more sensitive than a single scale of pain intensity.

Several authors have assessed functional ability of rheumatoid patients after exercise programs. Ekblom and colleagues (1975a & b, Nordemar et al 1976a & b) recorded the time it took subjects to walk a specific distance and to climb up and down a flight of stairs, and the height of foot stool they were able to climb. Nordemar (1981) utilized a self-administered questionnaire to evaluate the effects of a long-term training program. Others have used functional scales to investigate the general impact of the disease on daily activities (Fries et al 1980, Meenan et al 1980). Convery et al (1977) developed an interview questionnaire for use with polyarticular disabilities. They indicated that it had minimal intra- and inter-observer error, and correlated well with physician rating of functional impairment.

G. STRENGTH TRAINING PROGRAMS

In this section, the effects of both dynamic and isometric exercise programs are reviewed. Emphasis is on isokinetic rather than traditional isotonic exercise (see definitions). Training of both normal subjects and persons with pathology related to the musculoskeletal system is discussed. Review of the studies on exercise and RA occurs in a separate section at the end of the review of the literature.

ISOMETRIC TRAINING

A number of studies have shown that isometric training leads to changes in strength. The intensity, duration and number of contractions and the frequency of exercise sessions required for optimal improvements in strength have also been investigated and the opinions and results have changed over time.

Müller (cited in Hislop 1963) first reported that 1 daily contraction held for 6 seconds at two-thirds of maximal voluntary contraction (MVC) was adequate for maximal increases in strength (5% per week in normal subjects). The retention of the strength changes following cessation of training was longer with longer periods of training.

Liberson and Asa (1959) followed a similar format to that of the above mentioned study and found that an increased number of contractions per exercise session produced greater increases in strength than 1 contraction per day when training the hypothenar muscles. Bonde Peterson (1960), on the other hand, found no changes in isometric strength of elbow flexors or knee extensors following training with 1 or 10 maximal contractions. There was however a trend towards improvement when training with the greater number of contractions.

Hislop (1963) reported greatest increases in strength in elbow flexors when the muscles were trained twice daily with 15-second maximal isometric contractions. Persistance of gained strength up to 11 months after cessation of training suggested to the author that motor learning contributed significantly to the gains in strength.

Müller (1970), in a review article, concluded that rate of increase of strength decreases as one approaches his limiting strength. This pattern is not affected by age, sex, level of limiting strength or the muscle group trained. In contrast to his earlier statements, Müller reported that limiting strength was reached more quickly when contractions were maximal rather than submaximal. He also concluded that the number and duration of isometric contractions required for maximal results were specific to individual subjects. One may require as little as 1 daily 1-second contraction, but not more than 6 repeated trials of 5-second contractions.

Müller reported no loss in gained strength with a maintenance program of one 1-second maximal contraction once every 2 weeks. In one instance, he reported a loss of approximately 0.3% per day of the highest strength achieved when no maintenance program was followed after training ceased.

In a more recent study, Komi et al (1978) trained one of a pair of monozygous twins 4 times per week for 12 weeks with maximal isometric contractions of the knee. Compared to the control twin, the trained individual had a 20% increase in isometric strength of the trained leg and a 10% increase in the contralateral limb.

Gardner (1963) reported on the specificity of isometric training in relation to the training angle. Subjects trained their knee extensors isometrically at 25°, 45° or 65° of knee flexion for 6 weeks. Significant improvement occurred at the training angle only. Exercise was 1 contraction per day at two-thirds maximum 3 days per week.

Lindh (1979) trained 10 normal females with maximal isometric knee extension 3 times per week for approximately 5 weeks. One leg was trained at 15°, the other at 60°. Three sets of 10 maximal 6-second contractions were performed on each leg at each training session. The improvement in isometric strength was only at the training angle. The author also found that isometric training led to an increase in isokinetic peak torque and torque at 30° and at 60° at 30°/sec, but not at the higher test speed of 180°/sec. She concluded that the response to isometric training may be specific for angle and speed of contraction.

ISOTONIC TRAINING

DeLorme and Watkins (1948) were two of the first to outline a specific program of progressive resistance isotonic exercise for improvement in muscle strength. Resistance was increased as the muscle gained strength as measured by the isotonic 10 RM. The latter was also used as the training load.

Hellebrandt and Houtz (1956) and Hellebrandt (1958) further empasized the "overload" principle for improving muscle performance. They carried out a number of experiments trying different modifications of DeLorme's technique for isotonic exercise. They concluded that strength and endurance increase with heavy resistance repetitive exercise and that the critical factor determining progress is the amount of work done per unit time (ie, power), not total amount of work done. All their experiments involved 25 RM or proportions of it, and cadence was constant.

These authors (Hellebrandt and Houtz 1958, Hellebrandt 1958) also progressed exercise by increasing the tempo of the exercise rather than the load. They found gains in muscle performance as determined by work and power calculations and maximal resistance that could be lifted.

Hansen (1963) used 10 contractions of elbow flexors with a 1 RM load as training stimulus for his subjects. After 5 weeks, subjects had gains in isometric and dynamic strength and working capacity but not in isometric endurance. He concluded that maximal (1 RM) dynamic contractions were necessary to develop isometric strength.

Several studies were undertaken by Berger in the earlier 1960's to determine the best combinations of resistance, number of sets and number of contractions per set (cited in Clarke 1973, Berger 1962). The following programs brought similar and optimal results in 1 RM strength measurements: 2 RM for 6 sets, 6 RM for 3 sets and 10 RM for 3 sets. Even greater gains in strength were achieved when 10 repetitions of 1 RM were used for training (ie. the load was decreased slightly with each effort to allow for fatigue). As with isometric exercise, the results indicate that the isotonic training load should be of high resistance and low repetition to produce increases in strength.

DeLateur et al (1972a) compared isotonic and isometric training in a transfer of training design. They concluded from their findings that the best training for a specific type of contraction is that contraction itself. However, the authors measured number of repetitions or time to fatigue rather than strength. They also noted that the isometric group could perform as well as the isotonic group in the isotonic test although this transfer did not occur until the fourth day after cross-over to this form of exercise.

Thorstensson and colleagues performed a number of studies on dynamic strengthening (Thorstensson 1976, Thorstensson et al 1976b & c). Eight weeks of thrice weekly training with 3 sets of 6 repetitions of deep knee bends with weights led to increases in both isometric and isotonic strength of leg extension, although the latter changes were greater. Isometric muscle force exceeding 75% of pre-test MVC could be developed in a shorter time after training.

Two of the subjects were followed five months later (Thorstensson 1977). One of these subjects continued training but less often and with a lighter load; the other stopped training completely. The former had a further increase in 1 RM and a slight decline in the isometric test compared to his post-test values. The person who stopped training decreased in both tests, although only the isometric force had decreased to pre-training values.

MacDougall et al (1977,1979,1980a) reported on a series of experiments involving 5-6 months of isotonic training for elbow extensors. Improvement in isokinetic strength occurred in all studies, although only the more recent study included isokinetic contractions in the training program. However, variable resistance exercise apparatus was used (Nautilus).

Pipes (1978) compared training with constant resistance and variable resistance isotonic contractions of a number of different muscle groups. After 10 weeks of training all subjects had increases in strength as measured by a 1 RM. However, improvement measured on either apparatus was always greatest for the group that also trained on it.

Wilmore et al (1978) investigated the effects of a circuit weight training program, using loads of 40-50% 1 RM for a number of muscle groups. Subjects were to repeat each exercise as many times as possible in 30 seconds. Women improved in 1 RM for all tests and men in four out of eight tests. The load used in this study is well below what has been suggested for optimal strengthening and therefore it is not surprising that there were no changes in some tests. The improvements that did occur may be related to the subjects increasing the speed of their contractions as they tried to perform more repetitions in a specific time, a method suggested by Hellebrandt (1958) for progression of strengthening exercises.

Gettman et al (1978) employed a similar circuit weight training program and reported increases in 1 RM which were greater when tests were performed on the training apparatus.

Dons et al (1979) trained subjects with isotonically loaded knee bends with either 50% or 80% of their 1 RM. Increases in isotonic 1 RM and dynamic strength calculated per unit muscle cross-section were significant in the heavily loaded group only. The 50% group showed an overall increase in dynamic endurance. Neither group showed changes in isometric strength or isometric endurance.

Hickson (1980) studied combined endurance and strength training to determine possible interference of strength gains from the endurance component. The group receiving both types of training had increases in strength similar to the strength trained group until the seventh week, after which the strength of the former group began to decrease. He concluded that at the upper limits of strength training, endurance training may interfere with further gains in strength.

Gersten (1961) compared isometric and isotonic exercise programs in patients with weakness of the knee muscles. The percentage improvement in isotonic 1 RM was always greater than the improvement in isometric tension for all muscle groups trained regardless of the type of training contraction. Both forms of exercise led to similar changes. The author concluded that both isometric and isotonic training could improve muscle function in patients.

A few years later, Leach et al (1965) found that patients with knee injuries returned to military duty sooner after injury if they received isometric strength training than if they received isotonic training. Review of charts also indicated that the isometric group had fewer complaints of pain and effusion than the dynamic group.

ECCENTRIC ISOTONIC TRAINING

Although it has been determined that the maximal force exerted during an eccentric contraction is greater than maximal isometric or isotonic force (Doss and Karpovich 1965, Singh and Karpovich 1966), the effects of eccentric training have been studied by only a few.

Bonde Peterson (1960) noted that daily eccentric training for 36 sessions had no effect on isometric strength. Changes in concentric or eccentric strength were not reported.

Singh and Karpovich (1967) found increases in isometric, concentric and eccentric strength measurements of both agonists and antagonists after 8 weeks of eccentric training of the elbow extensors. They verified by EMG that both groups of muscles contracted during the training sessions.

Seliger et al (1968) trained athletes with eccentric or concentric contractions with close to maximal contractions (90-95% of concentric 1 RM for the concentric group and 145-150% for the eccentric group) for 13 weeks. Strength was measured concentrically only and improved equally in both groups. They suggested that eccentric contractions are more advantageous for strengthening as the energy expenditure is less.

In the same year, another study compared the two types of training (Mannheimer 1968). After 19 days of training with 2 sets of 5 repetitions, the eccentric group had significantly greater improvement than the concentric group, but at the end of 30 days of training, changes were similar for both. It appears that the author only tested the subjects with their training contraction.

Komi and Buskirk (1972), on the other hand, tested the concentric, eccentric and isometric strength of all their subjects. After seven weeks of training the elbow flexors, the eccentrically trained group improved in all tests. The concentrically trained group improved in the isotonic measurements only. Eccentric improvement was greatest in the eccentrically trained subjects. The authors noted that the latter had a drop in maximal eccentric tension during the first week, probably due to muscle soreness. In the same period, the concentric group made its greatest gains in tension of their training contractions.

Johnson and colleagues (Johnson 1972, Johnson et al 1976) reported no difference in the increases in strength resulting from a concentric or eccentric training program. They also suggested, in contrast to the study of Komi and Buskirk (1972), that eccentric exercise was performed with greater ease and less discomfort.

ISOKINETIC TRAINING

Thistle et al (1967) were the first to report on the effects of isokinetic training. Using normal subjects, they compared 8 weeks of this form of exercise with isometric and isotonic training of the knee extensors. The isokinetic group had a greater percentage increase in peak torque and total work ability. The method of measuring the latter was not described. As testing was performed isokinetically only, the results are not surprising. The authors suggested from their clinical observations that isokinetic exercise may have additional benefits - decreased pain and greater motivation.

Moffroid et al (1969) performed a similar study on normal men and women who received 4 weeks of training for quadriceps and hamstrings. The speed of training contractions for the isokinetic group was not mentioned, although testing was at 22.5°/sec. The authors reported significant increases in isometric and isokinetic torque for the isokinetic group. The isometric group improved in isometric tests only and the isotonically trained group had changes in isometric torque measured at 45° but not at 90°. The authors attribute the response of the isotonic group to their exercise load which was only maximal at the latter part of knee extension.

This study also had design problems. Exercise did not appear to be equated either by number of contractions, duration of exercise or intensity. The isometric and isokinetic groups performed 20 and 30 maximal contractions respectively. The isotonic group trained with 30 contractions, but only the last 10 were maximal effort.

Two years later this same group (Moffroid and Whipple 1970) examined the effect of speed on results of isokinetic training. One group trained at 36°/sec, the other at 108°/sec. The exercise sessions occurred 3 times per week for 6 weeks and involved 2 minutes of reciprocal contractions of knee flexors and extensors. In contrast to the study of Thistle et al (1967), there was no improvement in isometric torque (at 65° for knee extension and 45° for knee flexion). The group that trained at the lower speed (low power) had its greatest increases in peak torque of the quadriceps at 18° and 36°/sec, while the high power group improved fairly evenly among all speeds at and below the training speed. The latter group also had an increase in average power of the quadriceps as measured over 2 minutes of exercise at the training speed.

DeLateur et al (1972b) compared isotonic and isokinetic training in a double-shift transfer of training design. Forty-four females were trained with weights or on the Cybex at 72°/sec, working until fatigue. Half of each group transferred to the other method of training after 18 sessions while the remaining subjects continued with their initial form of training. Using number of repetitions till fatigue as the test measure, the authors found no difference among the four groups, and concluded that the Cybex did not provide an advantage over weights for strengthening of normal subjects. Unfortunately, their study did not test strength nor train for strength by the more acceptable procedure of progressive resistance.

Pipes and Wilmore (1975) also compared the effects of isotonic and isokinetic training. The two isokinetically trained groups had greater increases in isometric and isokinetic strength measurements than the isotonic group. The isokinetic group that trained at 136°/sec also had greater improvement in three of the isotonic tests. In a number of tests with both the isokinetic training device and the isokinetic testing device, the high speed group had greater gains in the high speed tests and in some of the low speed tests than the group trained at 24°/sec. All groups showed improvement in motor performance tests.

Lesmes et al (1978) compared the effects of isokinetic work bouts of different durations. They reported similar increases in peak torque at 0°, 60°, 120° and 180°/sec after 7 weeks of training with 10 6-sec work bouts or 2 30-sec work bouts at 180°/sec. Both legs showed an increase in work output for 6-sec or 30-sec work bouts at a velocity of 60°/sec or 180°/sec. At 180°/sec, the change was greater for the 30-sec trained leg. The increased work output during a 60-sec fatigue test was not significantly different in the two legs.

Using a similar training program, Costill et al (1979) found increases in peak torque for both legs with the greatest percentage change in an isometric contraction and lowest at the training speed of 180°/sec. Mean power output in a 60-sec test at this speed increased as a result of training, but the change was only evident in the first 30 seconds of the test.

In another study that used the contralateral leg as a control, women who trained for 5 weeks with 10 daily maximal isokinetic contractions at 60°/sec had increases in peak torque at all velocities measured from 0° to 180°/sec (Krotiewski et al 1979).

Two recent studies have confirmed earlier results concerning specificity of velocity of training. Coyle and Feiring (1980) had subjects train the knee extensors at 60° or 300°/sec. Improvement in extension torque only occurred at the training velocity in each group. Caiozzo et al (1980) examined the effect on the force-velocity curve of training at 96° or 240°/sec. Greatest changes were at the training velocities.

Isokinetic training has also been employed in the treatment of patients after knee surgery. Grimby et al (1980) compared isokinetic, isotonic and self- training on changes in quadriceps strength following knee ligament surgery. All patients improved in strength, but the largest increase occurred in the isokinetic group.

Pearson et al (1982) found that post-menisectomy patients recovered knee strength more quickly with a rehabilitation program involving early isokinetic training and quick advancement to higher and higher speeds even before full recovery had occurred at the slower speeds.

CONCLUSIONS ON STRENGTH TRAINING PROGRAMS

The findings indicate that training programs of either dynamic or isometric contractions can lead to increases in strength, but that changes may be specific to the type of training, particularly in relation to angle and velocity of contractions. Training contractions should be maximal and performed one to 25 times per session. There should be at least 3 training sessions each week for gains in strength, although less frequent exercise is required for maintenance of changes. Individual response to an exercise program will also be dependent on individual characteristics including initial strength as related to limiting or potential strength, and possibly muscle fibre composition.

All forms of exercise have been used successfully with pathological conditions, but choice of training method may depend on the specific muscle function disability.

EFFECT OF STRENGTHENING PROGRAMS ON MUSCLE SIZE

In earlier studies, muscle hypertrophy was assessed by measuring limb girth. The term appeared to be used almost synonomously with strength improvements in the discussion of the optimal exercise program (DeLorme and Watkins 1948, Hellebrandt 1958).

Both Noble (1971) and Clarke (1973) reviewed a number of studies on the effect of isotonic and isometric exercise on limb girth. Generally, hypertrophy was greater or occurred more frequently when isotonic contractions were performed. Noble (1971) concluded that isotonic contractions were better for producing hypertrophy and that 6-10 maximal contractions were more effective than fewer repetitions. Hislop (1963) found no changes in upper arm circumference with various protocols of differing frequency and duration, but her subjects performed isometric contractions of the elbow flexors. In the study of Komi and Buskirk (1972) there was an increase in the upper arm girth in the eccentrically trained group only.

More recently, Thorstensson et al (1976b) found no change in lower limb circumferences after 8 weeks of dynamic training. However, MacDougall et al (1977) found an 11% increase in arm circumference with longer duration (5 months) training on Nautilus equipment. The amount of improvement reported in the studies by Noble (1971) was as high as 3.3 cm with isotonic training but this change was in the thigh.

As measurement of limb circumference cannot distinguish between changes in muscle and fat composition, an absence of change in the measurement does not rule out muscle hypertrophy. Pipes (1978) reported decreases in absolute and relative body fat and skinfold thicknesses following 10 weeks training with either constant or variable resistance exercise. The limb circumferences also increased in the two groups. Pipes and Wilmore (1975) reported increases in limb circumference and decreases in absolute fat with both isotonic and isokinetic training, although the greatest changes occurred in the isokinetic high speed group (trained at 136°/sec).

Two studies reported increases in lean body weight following circuit weight training (Gettman et 1978, Wilmore et al 1978). In the latter study, increases in limb girth were also noted.

Women training for five weeks with isokinetic contractions at 60°/sec had increases in muscle thickness as measured by ultrasound and decreases in adipose tissue measured by calipers and ultrasound (Krotiewski et al 1979).

Computerized tomography was used to examine the thigh components of knee injured athletes during their recovery from surgery (Ingemann-Hansen and Halkjaer-Kristensen 1980). After 5 weeks of progressive resistance exercise, there was a 22% increase in the area occupied by the quadriceps.

In contrast to the above findings, Lesmes et al (1978) found no changes in thigh volumes, girth measures or skinfold thicknesses following 7 weeks of isokinetic training at 180°/sec. Leach et al (1965) also found no changes in thigh circumference in persons with knee injuries after isotonic or isometric strength training.

With the advent of the muscle biopsy, it has been possible to study the effects of exercise on the individual muscle fibres. Thorstensson et al (1976b) reported increases in the FT/ST area ratio after 8 weeks of isotonic training. Five to six months of isotonic training lead to similar changes with increases in size of both types of fibres (MacDougall et al 1979, 1980a).

Dons et al (1979) did not show significant changes in fibre size with 7 weeks of isotonic training with 80% or 50% of the 1 RM. However, they found a correlation between increases in dynamic strength per muscle cross-sectional area and number of FT fibres. They stated the results "indicate that a high content of FT fibres is a prerequisite for a successful strength training". If their conclusion is true, individual variation in fibre composition could account for differences in response to exercise in the studies reviewed. The findings of Houston and Thomson (1977) lend some support to this theory. They found no change in fibre size following 6 weeks of weight training with an isotonic 15 RM. Their subjects were endurance trained athletes who generally have a higher proportion of ST fibres. However, there were changes in dynamic strength.

Isokinetic training has also lead to changes in fibre size. Seven weeks of training with contractions of 180°/sec resulted in an increase in the percent of fibre area occupied by FTa fibres in the vastus lateralis of men (Costill et al 1979). Women who trained for 5 weeks at 60°/sec had an increase in area of type IIb fibres of the same muscle group (Krotiewski et al 1979). Houston et al

(1982) found increases in FTa and FTb fibres after 10 weeks of isokinetic training and a subsequent decrease in FTb fibre area only after 12 weeks of detraining.

In contrast, Ciriello et al (1982) found no changes in type I or type II fibre size after 4 months of isokinetic exercise. Grimby et al (1980) also found no significant changes in fibre size after 6 weeks of isotonic, isokinetic or self- training in patients who had had surgery for knee ligament injuries.

The mechanism of fibre hypertrophy has been determined from animal studies (Clarke 1973, Goldspink et al 1976). The fibre becomes bigger because of an increased number of myofibrils produced by longitudinal splitting. The sarcoplasmic reticulum and the T system increase in proportion to the change in myofibrillar content.

Penman (1969, 1970) in two studies on a limited number of human subjects indicated that strength changes occur as a result of an increase in the size of myosin filaments. He also concluded from his investigation that an increase in strength can occur without an increase in muscle size due to greater packing of contractile elements within a muscle cell. MacDougall et al (1979) reported decreases in volume density of mitochondria and mitochondria:myofibrillar volume ratio in humans after strength training. However, they attributed these findings to an increase in number of myofibrils rather than an actual loss of mitochondria.

Hyperplasia is another possible mechanism of increasing muscle size. Several studies on animals have suggested that fibre splitting may occur as a result of weight training or tenotomy of synergistic muscles (Gonyea 1980, Gonyea and Sale 1982, Ho et al 1977). The hyperplasia has always been reported in the presence of hypertrophied fibres and when the animals are lifting very heavy loads (Edgerton 1970, Gonyea et al 1977).

MacDougall et al (1980b) reported that elite powerlifters had significantly greater strength and arm girth than a control group who received 6 months of weight training. Because there were no differences in size or composition of fibres between the two groups, they suggested that hyperplasia had occurred in the elite athletes. Schantz et al (1981) concluded that hyperplasia was not a factor in girth measurements as they found a good correlation between the cross-sectional area of the vastus lateralis muscle determined by tomographic scanning and the mean muscle fibre cross-sectional area. Their sample included elite bodybuilders and physical education students.

Training studies on humans have shown no increase in the proportion of either type of fibre with a strengthening program (Thorstensson 1976, Costill et al 1979). Krotiewski et al (1979) reported a decrease in the percentage of type I fibres after isokinetic training but the decrease of less than 5% is smaller than the margin of error one would expect in this test.

It is possible that short term training has no effect on fibre population, but that long duration, very high intensity weight lifting may eventually lead to hyperplasia.

EFFECT OF STRENGTHENING PROGRAMS ON MUSCLE BIOCHEMISTRY

Very few studies have reported on the effect of strengthening exercise on the biochemistry of muscle. MacDougall et al (1977) reported increases in creatine, CP, ATP and glycogen concentrations after 5 months of heavy resistance training of the elbow extensors. Houston and Thomson (1977) also found an increase in ATP in endurance athletes with 6 weeks of isotonic training. Eight weeks of dynamic training produced no changes in enzyme activity of ATPase, CPK and phosphofructokinase (PFK), but an increase in myokinase (MK) (Thorstensson et al 1976b, Thorstensson 1976). A 12 week isometric training program produced increases in activity of malate dehydrogenase (MDH) and succinate dehydrogenase (SDH), both oxidative enzymes (Komi et al 1978). There were also decreases in lactate dehydrogenase (LDH) and CPK, and an increase in hexokinase (HK). In contrast, Krotiewski et al (1979) reported increases in LDH as well as in MK following 5 weeks of isokinetic training at 60°/sec.

In the study of Costill et al (1979) involving isokinetic training, legs trained with 30-sec work bouts had increases in activity of phosphorylase, CPK, PFK, MDH, SDH and MK. The legs trained with 6-sec work bouts had increases in PFK only. They concluded that duration of an exercise bout rather than total work performed is the stimulus for increased muscle enzyme activity. However, in spite of the biochemical difference between the two legs there was no difference between them in the fatigue test. The authors suggested that fatigue in maximal muscular effort is not dependent on the muscle's anaerobic potential as measured by glycolytic and ATP-CP enzyme activities.

Houston et al (1982) found that four weeks of dynamic strength training and then four weeks of detraining had no significant effect on the activities of ATPase, creatine kinase, glycolytic enzymes and oxidative enzymes. Similarly, Grimby et al (1980) reported no changes in concentrations of ATP and CP and enzyme activity of ATPase, MK and LDH of the quadriceps after 6 weeks of strength training following knee ligament surgery.

It is difficult to form conclusions from so little information, but it is surprising to see changes in oxidative enzymes which should not be involved in exercise of such short duration and high intensity. The subjects in the study of Komi et al were between 13 and 15 years of age and were still developing. Once weekly testing with submaximal exercise and fatigue loads in their study may have been adequate to train the aerobic system.

EFFECT OF STRENGTHENING PROGRAMS ON ELECTROMYOGRAMS

A few authors have examined the effect of training on EMG during maximal and submaximal muscle contractions. A study comparing eccentric and concentric training showed no change in integrated EMG (IEMG) and no change in the IEMG:tension ratio with any kind of contraction (Komi and Buskirk 1972). Two studies, one with isometric training (Komi et al 1978), and one with isotonic training (Thorstensson et al 1976c) found a diminished IEMG:tension ratio after training. The isometric program produced an increase in maximal IEMG, while the isotonic program showed trends towards a decrease in this measurement.

Again, it is difficult to make conclusions from a limited number of studies. However, a decrease in IEMG:tension ratio implies that improvement in strength is in part produced by an increase in maximal tension that can be produced by each motor unit. Changes in maximal IEMG could indicate changes in pattern of fibre recruitment following training. The latter is further supported by the findings of Milner-Brown et al (1975) who used EMG to measure synchronization of firing of motor units in the first dorsal interosseous muscle. After 6 weeks of training with daily maximal contractions, synchronization increased.

H. MUSCLE FIBRE RECRUITMENT

It has been recognized for over one hundred years that mammalian skeletal muscle has at least two different types of fibres (Peter et al 1972, Buller 1975). Now three distinct motor units have been described. One contains the type I muscle fibre, also called slow twitch (ST) or slow oxidative (SO). It has a low peak tension, slow contraction time and high resistance to fatigue relative to the fast twitch (FT) fibre. The latter, also called fast glycolytic (FG) or type II, has a high peak tension, fast contraction time and poor resistance to fatigue. A third type of fibre is intermediate in properties and is commonly called IIa, FTa or fast oxidative glycolytic (FOG) (Buller 1975).

The main theory on the order of recruitment of the different fibre types follows the "size principle" (Henneman and Olson 1965). It is believed that the smaller motor units associated with the slow twitch fibres are recruited first, and as more motor units are needed for the muscle performance, they are recruited in order of size.

Studies on fibre recruitment in humans are limited by the methods available. Fibre composition or size has been correlated with particular performances or compared in different athletes and sedentary individuals. More direct evidence has been obtained by studying the effects of exercise on glycogen depletion in the fibres or by observing EMG from a small number of distinct motor units. Although these methods have problems, they do provide qualitative information on the recruitment of the different motor units, data that could assist in the choice of exercise for specific muscle fibres. In the case of persons with RA, if there is greater atrophy of the FT fibres, recruitment of them in exercise may help to reverse the situation and improve the function of these patients.

Training studies which examine the effect of exercise on the different muscle fibre types also enhance our knowledge of recruitment. These have been discussed previously.

RECRUITMENT DURING ISOMETRIC CONTRACTIONS

Several investigators have found a positive correlation between the percent of FT fibres and/or the percent area occupied by these fibres in the vastus lateralis, and the maximal isometric force produced by the knee extensors (Tesch and Karlsson 1978, Komi and Karlsson 1979, Komi et al 1977). Others (Thorstensson 1976, Gregor et al 1979) have not reported these correlations. Correlations have been lower in females (Komi and Karlsson 1979) and when fibre composition is related to strength of two leg extension (Thorstensson 1976, Hultén et al 1975). Clarkson et al (1982) found that maximal isometric strength was related more to body weight than percent of fast twitch fibres.

Secher et al (1976) demonstrated a decrease in the ratio between two and one leg extension forces with selective blocking of type II fibres (with d-tubcurarine), and a slight increase in the ratio with blocking of type I fibres (with decamethonium). The results indicated a greater recruitment of the type II fibres during one leg isometric exercise. However, athletes trained in activities requiring maximal leg work are able to produce greater relative two leg force (Tesch and Karlsson 1978, Secher 1975), and possibly recruit a greater proportion of their FT fibres with bilateral contractions, than the untrained.

Repeated maximal isometric extensions of the legs have resulted in maximal depletion of glycogen in the type IIb fibres with the least depletion occurring in the type I fibres (Secher and Nygaard-Jensen 1976).

There has been greater controversy on the role of the FT fibres in submaximal isometric contractions. Gollnick et al (1974 & 1975) followed the glycogen depletion pattern of the vastus lateralis with increasing intensity of contraction of the quadriceps, and concluded that predominantly FT fibres are recruited at force levels greater than 20% of the MVC. Studies recording the electrical activity of individual motor units suggest a more gradual increase in the recruitment of FT fibres with increases in muscle force. As muscle force becomes greater, motor units are recruited in ascending order of the contraction force they generate (Tanji and Kato 1973a, Maton 1976, Milner-Brown et al 1973) and the size of their action potentials (Tanji and Kato 1973a, Maton 1976). Phasic units, those with higher optimal and maximal discharge frequencies, are progressively activated (Hannerz 1973), and there is a linear rise in their frequency of discharge (Gydikov and Kosarov 1974, Tanji and Kato 1973b) with increasing contractile force.

Speed of force production of an isometric contraction may also be important in determining the degree of FT recruitment at submaxinal levels of contraction, and could account for the differences in the results reported above. Recording from single motor units, Tanji and Kato (1973a) noted that as maximal muscle force was achieved faster, the same motor unit was recruited at a lower tension. Using similar techniques, it was found that phasic motor units of the biceps increased their firing frequency exponentially with change in speed of force development (Gydikov and Kosarov 1974). Recordings from tibialis anterior showed no recruitment of these units with weak contractions unless there was a rapid initiation of the contraction from complete relaxation (Grimby and Hannerz 1968). Warmolts and Engel (1973) recorded from areas of muscle in patients with neuropathies and found that the sampled regions contained approximately 95% type II fibres. The fibres were only activated by rapid vigorous and briefly sustained contractions.

Viitasalo and Komi (1978) reported that the time taken to produce a required percent of isometric MVC was correlated with the proportion of FT fibres in the contracting muscle for all forces below 90% MVC.

RECRUITMENT DURING ISOTONIC CONTRACTIONS

Secher and Nygaard-Jensen (1976) reported that both one and two leg dynamic extension produced greater glycogen depletion in the type IIa and IIb fibres than in the type I. However, there was less total glycogen depletion with the two leg exercise. Komi and Viitasalo (1977) found no differences in the glycogen depletion of the ST and FT fibres of the vastus lateralis following either 40 maximal eccentric or concentric contractions of extensors of both legs.

Several investigators have reported positive correlations between percent of FT fibres and/or their relative area in the vastus lateralis and various indices of performance of maximal isokinetic knee extension at 180°/sec. These indices include peak torque (Thorstensson 1976, Thorstensson & Karlsson 1976, Thorstensson et al 1976a, Nilsson et al 1977, Komi and Tesch 1979), work and power (Nilsson et al 1977), rate of fatigue (Thorstensson & Karlsson 1976, Nilsson et al 1977, Komi & Tesch 1979), and relative increase in peak EMG:peak torque (Komi & Tesch 1979) and IEMG:work (Nilsson et al 1977) ratios and lactate concentrations in muscle (Tesch et al 1978) after repeated contractions. The authors indicated that exercise at this speed involves substantial recruitment of the FT fibres. Failure to maintain a high force output after repeated contractions would be due to the fatigue of these high tension producing fibres.

Others have reported that subjects with a greater percentage of FT fibres produce greater absolute torques at speeds of 96°, 192°, and 288°/sec (Gregor et al 1979) and achieve contractions of higher velocity (Thorstensson et al 1976a). Gregor et al (1979) also reported that the percentage difference in torque produced at 0° and 96°/sec was negatively correlated with the percent ST fibre area ($r=-0.52$). With a greater area occupied by ST fibres, the torque-velocity curve was flatter between 0° and 96°.

From recordings of single motor units during muscle contraction, Hannerz and Grimby (1973, Grimby and Hannerz 1968 & 1977) concluded that phasic units will be recruited for rapid contractions, especially in alternating movements. Using similar techniques, Maton (1980) reported that a given motor unit can discharge during a static or dynamic contraction and that the firing rate and recruitment in both types of contractions are dependent only on the external force.

Recently, Lesmes et al (1979) compared glycogen depletion with isokinetic exercise at 60°/sec and at 300°/sec. The depletion was similar in fast and slow twitch fibres at the slow speed but was much greater in the FT fibres following exercise at 300°/sec.

From the studies reviewed, it appears that ST fibres are generally recruited first, and that FT fibre recruitment increases as force or speed of contraction become greater. The optimal combination of speed and force for the greatest recruitment of the FT fibres has not been established, but perhaps it is the point at which the muscle can produce the maximal power. Factors such as individual fibre composition, glycogen content of muscle, and degree of training probably also have an effect on fibre recruitment.

I. STRENGTH TRAINING PROGRAMS FOR RHEUMATOID ARTHRITIS

It is difficult to evaluate the effects of an exercise program on patients with rheumatoid arthritis because of the fluctuating nature of the disease and the usual simultaneous implementation of several forms of therapy such as medication, injections, rest and exercise. Because of these difficulties, some investigators have examined the effects of an entire treatment program as opposed to only one aspect of it. Lowman (1958), Duff et al 1974), and Karten et al (1973) reported improvement in the ability to perform daily activities in a proportion of patients participating in rehabilitation programs and followed for periods up to five years. The study with the youngest patients also recorded improvement in the greatest percentage of subjects. These studies did not evaluate the change in specific parameters that might contribute to the improved function such as decreased pain, increased strength, or increased range of motion.

Results of several studies have indicated that exercise might detrimentally affect the person with RA.

Partridge and Duthie (1963) found that hospital patients with RA had a greater decrease in disease activity if joints were completely immobilized than if patients were on bed rest but performed active exercise daily. Smith and Polley (1978) reviewed several studies that reported similar results - greater improvement of disease activity with rest and immobilization and faster deterioration with increasing and heavier activity. However, Mills et al (1971) found no difference between a program of bed rest and one of ad lib activity on their effect on disease activity in hospitalized RA patients.

Hollander and Horvath (1949) found that 10 to 15 passive movements of the rheumatoid knee increased the joint temperature which is usually elevated in RA joints even at rest (Horvath and Hollander 1949). Harris and McCroskery (1974) have demonstrated in in vitro studies, that an increase in temperature increases the activity of collagenase, an enzyme involved in the degradation of cartilage collagen.

As indicated previously, patients can experience pain during exercise, although the pain has not always been associated with level of strength (Tiselius 1969, Ekblom et al 1974).

In dogs with experimental crystal-induced arthritis, synovial fluid and leukocyte count increased with passive movement of the joint (Agudelo et al 1972). In addition, exercise in RA has produced decreases in oxygen tension and pH indicating a possible decrease in the nutrition to the joint during exercise (Lund-Olesen 1970). Lund-Olesen (1970) suggested a cyclic series of events with the anoxia leading to cell death and release of lysosomal enzymes, events which produce increased leukocyte migration into the joint, a greater oxygen consumption and greater anoxia.

Jayson and Dixon (1970) found that during both passive and active exercise, the intra-articular pressures in rheumatoid arthritis were significantly higher than in normal subjects. They indicated that the pressures may be high enough to cause cystic bone lesions, synovial cysts or joint rupture.

None of these studies examined the long term negative effects of exercise nor weighed these against the possible benefits of exercise to joint and muscle function.

Liberson (1961), reporting on the results of brief isometric exercise in a number of subjects, indicated that the one RA subject in his sample had a 'favorable' response.

Machover and Sapecky (1966) examined the effect of 7 weeks of thrice daily 6-second isometric contractions on the strength of the quadriceps of 11 male patients with rheumatoid arthritis. They reported a 23.3% gain of strength of the exercised limb compared to a 17.6% increase in the contralateral control leg. They did not provide statistical analysis of their results. In addition, the improvement might have been due to the rest the patients received as inpatients, and the intra-articular steroid injections received by three subjects. The authors did not specify the severity of the disease in their patients. However, they did note that the exercise did not lead to an increase in joint swelling or pain.

Two studies reported no change in strength of the quadriceps in rheumatoid patients receiving isometric exercises. Cuddigan (1973) compared his experimental subjects to a normal group that received no exercise and were in a much younger age bracket than the patients. His exercise routine was not well described and was simply termed an "intensive physiotherapy program".

Luckhurst et al (1974) had similar results when comparing patients with RA to those with osteoarthritis, post menisectomies, or normal knees. All subjects received 4 weeks of progressive resistance isometric exercises for the quadriceps. Both isometric 1 RM and 10 RM improved in all except the rheumatoid group. Although pain on movement decreased and there was no change in frequency of effusions in the rheumatoid knee, these patients took longer to walk 50 feet after the experimental period. Performance on stairs improved slightly. The subjects with RA missed several treatment sessions during the study because of pain and fatigue.

The majority of the studies on isotonic training in RA have shown improvements in strength. McLaughlin and Reynolds (1970), however, found no improvement in such tests as grip and pinch strength, pronation and supination torque, ADL (activities of daily living) and dexterity activities, with a program of isotonic hand exercises. Resistance to movement was not provided in this program, and the opposite hand of each patient was used as the control.

Ekblom et al (1975a) studied the effects of a 6 week physical training program on a group of hospitalized rheumatoid patients. The program included interval training on a bicycle ergometer and muscle strengthening on a quadriceps table (isotonic contractions). Compared to a control group of RA subjects, the training group improved significantly in walking and stair tests, in height of foot stool they could climb, and in physical fitness as measured by maximal oxygen consumption, heart rate at a specific work load and maximal work performance. Both isometric and dynamic muscle strength of quadriceps and isometric strength of elbow flexors and ankle plantar flexors improved in the exercise and control groups, with no significant difference between groups. Both groups had received "routine physiotherapy" consisting of muscle strengthening and joint mobility. The authors reported no change in joint swelling and pain in either the experimental or control group.

These patients were followed up 6 months later (Ekblom et al 1975b) and it was found that those who continued with some form of exercise 4 times per week showed no change in muscle strength. Those who exercised only 2 times per week or less had a decrease in dynamic muscle strength of the legs. Some members of the control group had commenced a training program at home and had an increase in isometric muscle strength in both arms and legs. The remainder of the control group showed a decrease in physical performance with no changes in muscle strength. Again, there was no change in joint status.

The same group of investigators (Nordemar et al 1976a) studied the effect of this physical training and strengthening program on muscle fibre size. After 6 weeks training, there was no change in fibre composition in the vastus lateralis. However, both types of fibres increased in size, the fast twitch increasing more (35%) than the slow twitch (23%). Changes in physical performance and strength were in agreement with their previous findings.

A longer, but less intensive exercise program (Nordemar et al 1976b) resulted in a 12% improvement in strength, but no change in fibre size. The authors also reported a significant correlation between isometric strength and size of fast twitch fibres in their patients. The correlation was greater after training (r=0.817) than before (r=0.535). There was no increase in muscle or joint inflammation.

Nordemar and colleagues (1981, Nordemar 1981) have since followed rheumatoid patients receiving physical training for 4 to 8 years. The patients followed a variety of training modes including swimming, skiing and cycling. Some of the patients participated "more or less" regularly in a group that exercised on a bicycle ergometer and performed strengthening exercises for the lower extremities.

Compared to a control group that had no regular exercise, the training group had a less pronounced progression of radiological changes of the joints. The training group also improved their quadriceps torque, biceps torque and performance on a stair test. ADL performance as assessed by a questionnaire was significantly better in the trained group.

There is always a possibility in such a study that subjects whose disease is better will tend to exercise more, rather than the exercise affecting the disease progression. Some of the subjects changed groups in the first part of the study because they were not following the exercise or non-exercise program outlined for their group.

Harkom et al (1982) also had their subjects on aerobic training, but did not include strengthening exercises in their program. They did not find any change in knee extension torque measured on an isokinetic dynamometer.

To summarize, the results of studies evaluating the effect of exercise on strength of persons with RA have been conflicting. The majority of the studies have had design problems relating to choice of controls, changes in overall treatment program and lack of specificity of the training exercise. It is encouraging, however, that some of the more recent studies have indicated that dynamic exercise can lead to muscle hypertrophy, increase in muscle strength, and a decrease in progression of the disease. None of the studies compared the effects of different types of strengthening programs.

III. METHODS

A. SUBJECTS

Subjects were females between the ages of 23 and 59 who fulfilled the criteria for classical or definite rheumatoid arthritis (Appendix A). All were in anatomical stage and functional class II (Appendix B). All had symptoms of arthritis related to the knee. These included one or more of the following:

1. stiffness of knee or thigh
2. pain, aching or tenderness of the knee
3. swelling of the knee
4. atrophy of quadriceps
5. "giving way" of the knee

Persons meeting any of the following criteria were not included in the study:

1. commenced treatment with myochrysine, penicillamine, azathiaprine, or chloroquine less than 6 months prior to the onset of the study
2. stopped myochrysine, penicillamine, azathiaprine, or chloroquine less than 3 months prior to the onset of the study
3. received in the past or were receiving systemic corticosteroids
4. received an intra-articular injection of steroid or radioactive gold in the 3 months prior to the onset of the study

5. were suffering from cardiovascular disease including hypertension, previous myocardial infarction, angina or any cardiac ailment for which they were receiving treatment.
6. had a musculoskeletal disease other than rheumatoid arthritis.

B. RESEARCH DESIGN

The study was a randomized control-group, pre-test/post-test design (Campbell and Stanley 1967) with the exception that the subjects were selected nonrandomly for admission to the study. All subjects underwent pre-tests, were stratified on the basis of absence or presence of knee swelling determined clinically, and then were randomly assigned to one of three groups. One experimental group received isometric training, one experimental group received isokinetic training and the third group acted as control subjects and received no training. The two exercise groups were tested for pain and swelling at each training session. All pre-tests were repeated again at the end of the training period. Midway through the training program, the subjects in the exercise groups were tested for joint activity, pain and function. An outline of the design is illustrated in figure 3.1.

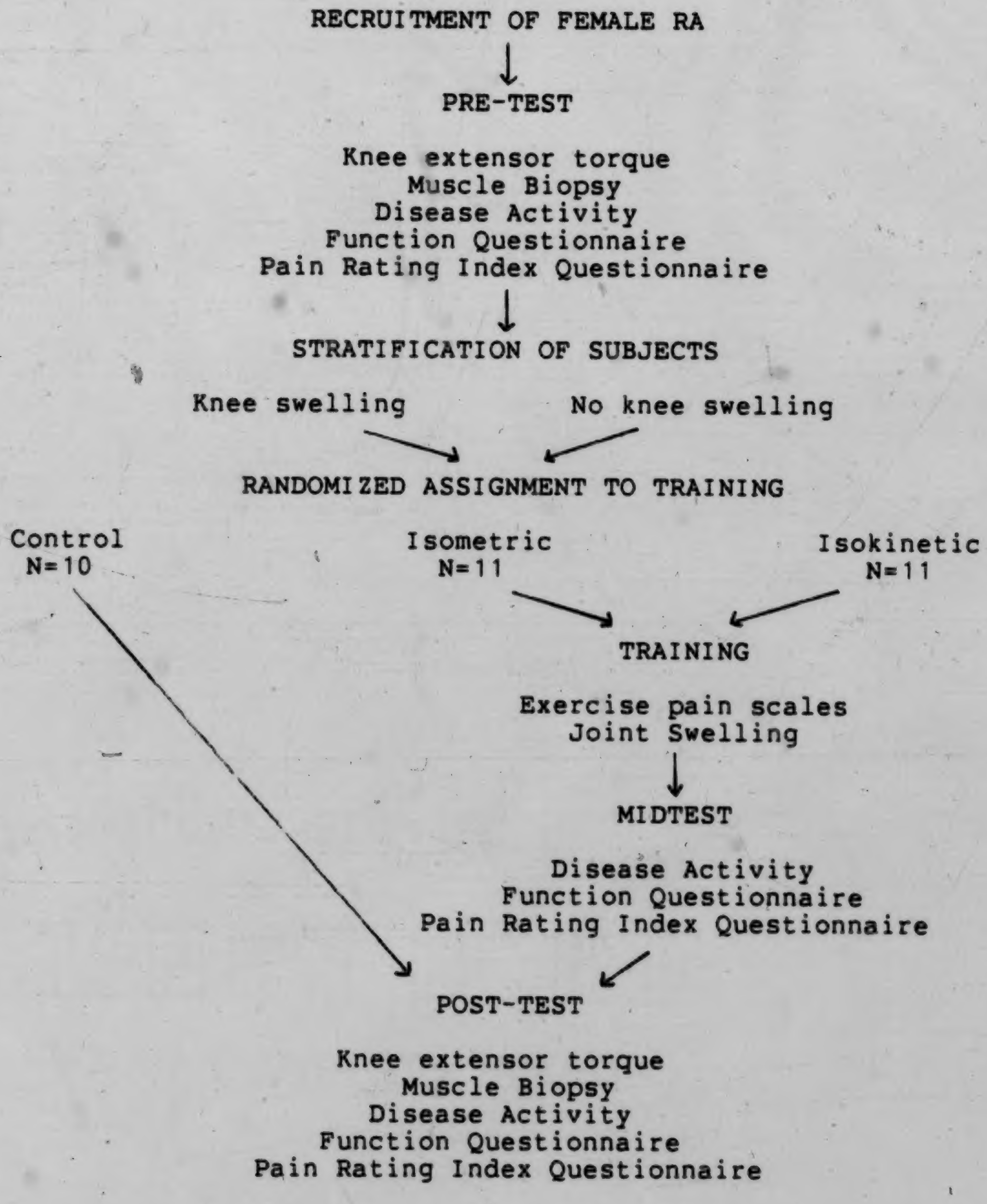
RECRUITMENT OF FEMALE RA
PRE-TEST
Knee extensor torque
Muscle Biopsy
Disease Activity
Function Questionnaire
Pain Rating Index Questionnaire
STRATIFICATION OF SUBJECTS
Knee swelling
No knee swelling
RANDOMIZED ASSIGNMENT TO TRAINING
Control
N=10
Isometric
N=11
Isokinetic
N=11
TRAINING
Exercise pain scales
Joint Swelling
MIDTEST
Disease Activity
Function Questionnaire
Pain Rating Index Questionnaire
POST-TEST
Knee extensor torque
Muscle Biopsy
Disease Activity
Function Questionnaire
Pain Rating Index Questionnaire

Figure 3.1: Research Design

C. TEST PROCEDURES

DISEASE ACTIVITY

The following indices were used in the evaluation of disease activity: duration of morning stiffness, time of onset of fatigue, grip strength, number of painful joints, and number of swollen joints. The methods are described by Lansbury (1958).

FUNCTION

Subjects answered a questionnaire concerning their ability and independence in a number of daily activities (Appendix D).

PAIN

The overall pain of all subjects was assessed pre- and post-study by means of a pain rating index (PRI) based on the rank values of words describing pain (Melzack 1975) (Appendix E). The exercise groups were also evaluated for pain midway through their training programs.

Pain experienced during the exercise sessions was rated by the experimental subjects in two ways. They were asked to indicate the severity of their pain on a continuous line scale of 10 cm. They also rated their exercise pain on a 15 point scale adapted from the perceived exertion scale of Borg (Eklund 1977) and renumbered to have a lowest value of 0. (See Appendix F for pain scales).

KNEE SWELLING

Swelling of the knee was measured before and after each exercise session by measuring the circumference of the knee immediately above the patella with the knee extended and the patient lying in a supine position.

MUSCLE FIBRE COMPOSITION AND SIZE

A biopsy sample was taken from the vastus lateralis of the weaker leg after all other pre-tests had been completed and before commencing training. A second biopsy was performed after the completion of the final strength tests. The biopsies were taken using a Bergström needle by the method described by Bergström (1962). After an injection with local anaesthetic, a small incision was made on the lateral aspect of the thigh approximately midway between the knee and the hip. The biopsy needle was inserted in the incision through the ilio-tibial band to the vastus lateralis. The inner cylinder of the needle was pushed in while the outer needle was kept in place. Counter pressure was applied with the other hand to the antero-medial aspect of the thigh.

The biopsy samples were mounted on cork, immediately frozen in isopentane cooled in liquid nitrogen and then stored at -80° C until the time of staining.

In preparation for staining, muscle tissue samples were warmed to -20° C in the cryostat and the cork mounted on a chuck. Sections of 10 *u* thickness were cut in the cryostat and mounted on coverslips. Each section was checked under a microscope to ensure that a cross-section had been obtained, and then left to air dry for at least one hour before staining.

Staining for ATPase was done by the method of Guth and Samaha (1969) (Appendix G) with pre-incubation at pH 10.4 and incubation at pH 9.4.

To measure fibre size, photomicrographs of the muscle sections were taken and the film processed as 8" x 10" prints utilizing the same exposure time, aperature and distance for all prints of a film. For calibration purposes, a micrometer was placed under the microscope at the same setting and photographed. The areas were calculated by the least diameter technique (Dubowitz and Brooke 1973) using circles of various diameters to facilitate measurement. The value used for analysis was the average area of each fibre type determined from 16 or more of each of fast twitch and slow twitch fibres.

STRENGTH TESTING

Testing of strength took place on three days with a day between each test session both before and after the training programs. All testing was done on a Cybex II isokinetic dynamometer which was calibrated prior to each test session using the method suggested by the manufacturer (Appendix C).

Figure 3.2 illustrates subject and apparatus positioning for both isometric and dynamic torque

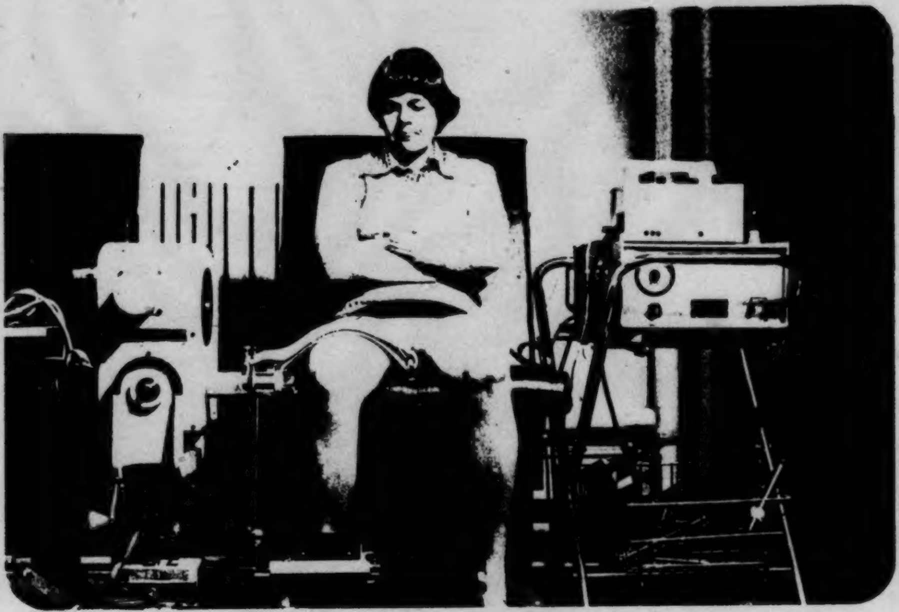

Figure 3.2: Strength testing set-up

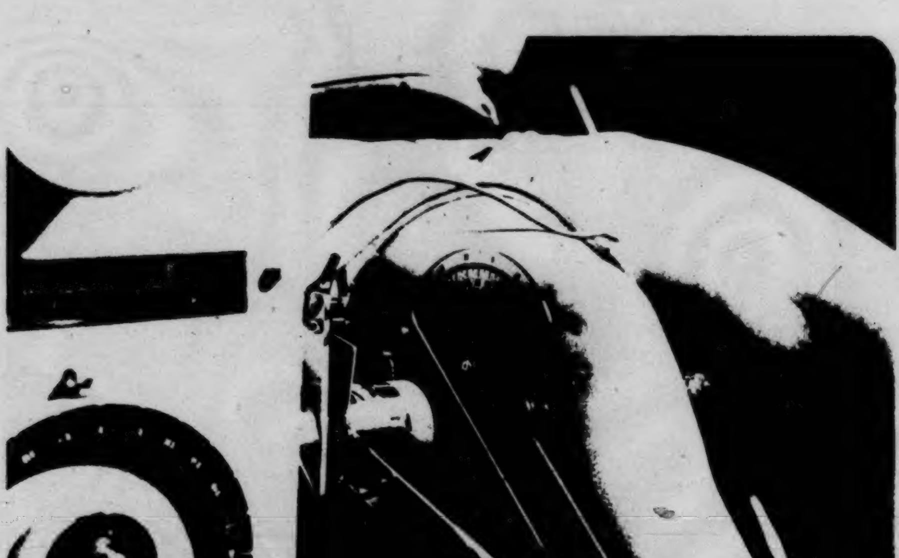

Figure 3.3: Measurement of knee angle

measurements of the quadriceps. Varying thigh lengths were accommodated with removable back supports. Stabilization was provided by a strap around the pelvis and another on the thigh of the leg to be tested. Subjects were asked to place their arms in a position that was comfortable for them, and to keep them in the same position for all tests.

The position of the Cybex II dynamometer was adjusted to align the axis of rotation of the input shaft with the centre of the lateral joint line of the knee when the knee was in a rest position at approximately 90° of flexion. The length of the lever arm was adjusted so that the padded strap could be attached comfortably around the lower leg of the subject. The distance of the input shaft from the lateral side of the knee was adjusted until the subject could extend the knee through the test range smoothly and comfortably without excessive medial-lateral movement of the leg.

A microswitch was put on the input shaft of the dynamometer and adjusted to record when the knee angle of the subject was 30° from full extension. This angle was measured with a plastic goniometer, the centre of which was placed at the lateral joint line of the knee and the arms aligned with the greater trochanter of the femur and the lateral malleolus (Figure 3.3). The measurement was taken as the subject was contracting isometrically against the arm of the Cybex to account for the accommodation to movement provided by the padded strap and the input shaft.

Testing of both legs was performed on all subjects. The order of testing the weak and strong leg was random. Isometric torque was recorded in three different knee positions - 30°, 60° and 90° - which were measured with a goniometer as described above. The method of Perrine and Edgerton (1978) was used to record torque at 48°, 96°, 144° and 192°/sec. At the slower speeds, the subjects were asked to produce maximal torque of knee extension only as the knee approached the 30° position. This point could be judged by the subjects' following the movement of the microswitch on the input shaft as they extended their knee. At speeds of 144°/sec and faster, the subjects exerted maximal effort throughout the range from approximately 90° to full extension. At the two slower speeds, the torque was also recorded in the standard way, ie, the subject was asked to extend his knee as hard and as fast as he could throughout the full test range. The performance commands for maximal effort through range were "ready and kick", for isometric, "ready and push", and for the Perrine and Edgerton method at slow speeds, "start extending and kick" (as the leg approached the 30° position).

At each test session, the tests were repeated three times and the best result used for the measurement and calculations. The same tests were repeated at each session and the final best values used for analysis for both pre- and post-tests.

All torque curves were recorded on the heated stylus recorder provided by the manufacturer.

The following are the measurements and calculations determined from the torque curves:

1. torque at 30° (highest value obtained by either method)
2. power = torque at 30° x velocity x 2pi x $360^{\circ -1}$
3. peak torque (standard value)
4. work = area under the entire torque curve (for all curves where maximal effort was exerted through the full range)
5. power = work (above) x time^{-1}
6. work = area under the torque curve between 15° and 75° (for all curves where maximal effort was exerted through the full range)
7. power = work (above) x time^{-1}

Area of the torque curves and work and power equivalents were measured on a Hewlett Packard digitizer (Appendix H).

D. TRAINING PROGRAMS

CONTROL GROUP

The control group received no exercise program but was tested before and after the seven week program in the same manner as the other two groups. The subjects in this group and in the two exercise groups were requested to maintain their normal activities.

ISOMETRIC GROUP

Subjects in the isometric group were trained with isometric contractions of the quadriceps three days a week for seven weeks. The training set-up was the same as described for testing. With the speed of the Cybex II set at 0°/sec, the subject extended his knee maximally against the input arm for three seconds, once at each of the knee angles of 30°, 60° and 90°. There was one minute between the beginning of each contraction while the apparatus was adjusted to the next position. Both knees were trained, the order of training of the legs being random at each session.

ISOKINETIC GROUP

The training situation for the isokinetic group was the same as that for the isometric group except that the former performed contractions of the quadriceps through a knee range of approximately 90° at 180°/sec. Six repetitions were done in succession with a minute between the commencement of each of three sets. Thus, time periods for work and rest were the same for both groups.

E. HANDLING OF DROPOUTS

It was made clear to all patients at the beginning of the study that they were being asked for a seven week committment of thrice weekly treatment plus an additional two weeks of testing. If a training session was missed, all attempts were made to make it up the same week. If a subject missed more than three visits in total, she was considered a dropout from the study.

F. DATA ANALYSIS

The following were the dependent variables and their scale of measurement:

1.	Torque	Nm
2.	Power	Watts
3.	Work	Joules
4.	Fibre Size	U^2
5.	Pain	mm Likert scale
6.	Swelling	cm

Disease activity parameters were the following:

1.	Morning Stiffness	Hours (hr)
2.	Fatigue	hr
3.	Grip Strength	mm mercury (mm Hg)
4.	Painful Joints	Frequency
5.	Swollen Joints	Frequency

A two-way analysis of variance (ANOVA) was used to analyze data on torque, power, work, fibre size, disease activity measurements and function. In all cases one factor was a repeated measure. The Neuman-Keul procedure was used for post-hoc analysis.

Pain and swelling occurring with the exercise were analysed by averaging values from seven consecutive sessions and performing analysis of variance as above on the resulting values.

Pearson product moment correlations were performed between specifically selected variables, eg., comparison of the two exercise pain scales.

G. ETHICAL CONSIDERATIONS

The study was submitted to the Ethics Committees of the Faculties of Medicine and Physical Education and Recreation, receiving approval in both cases.

Informed consent was obtained from all subjects before their admittance into the study (Appendix I). The possible benefit a subject could receive through participation in the study was an increase in strength and function of the knee. However, the subjects were also informed that they might have no increase in strength and could have added discomfort from the treatment.

If subjects objected to having a repeat biopsy, no pressure was put on them to undergo this procedure.

Participation in the study did not affect the subjects' medical treatment. If they had any concerns about their arthritis and medical treatment during the study, they were referred back to their rheumatologist for review.

IV. RESULTS AND DISCUSSION

This chapter begins with a brief description of the subjects and their course through the study. Presentation of results is divided into five main sections:

1. data derived from Cybex testing
2. data on muscle fibre types and area
3. disease activity parameters
4. pain and function scales
5. exercise pain and swelling

The findings are discussed as they are presented. At the end of the chapter, the major results of each section are summarized and their interrelationships discussed. Most of the data was analysed using a two-way ANOVA. The post-hoc differences were determined using the Newman-Keul procedure. In cases of unequal numbers per group, the harmonic mean of observations was employed for the latter. (Ferguson 1971). When results are reported to be significant, the probability level is $p \leq 0.05$ unless otherwise stated. All statistically significant values in tables are underlined.

A. SUBJECTS

Thirty-two subjects were entered into the study and 26 of these underwent the pre-test muscle biopsy. Only one of the latter refused to have a repeat biopsy.

Three persons in each exercise group missed one or more treatment sessions. In total, seven days were missed by the

TABLE 4.1

SUBJECT CHARACTERISTICS*

	GROUP		
CHARACTERISTIC	CONTROL	ISOMETRIC	ISOKINETIC
	n=10	n=10	n=11
Age (yrs)	43.6	40.9	39.5
	(26-59)	(23-56)	(26-55)
Duration of	5.5	9.8	4.2
disease (yrs)	(0.7-11)	(1-23.5)	(0.5-19)
Height (in)	63.7	64.3	63.2
	(60-69.5)	(60-68)	(59-66)
Weight (lbs)	131.5	125.4	136.2
	(92-167)	(114-157)	(115-160)

*values are means with range in brackets

isokinetic group and five in the isometric group. An additional person in the isometric group completed 21 exercise sessions, but with a two week interruption in the middle. Her data were not included in the analysis. Subject #19 in the isokinetic group hurt her back between the final treatment session and the post-test. Her strength test results were not analysed.

One person in each exercise group received an intra-articular injection of corticosteroid in a joint other than the knee during the study.

Subject characteristics are presented in table 4.1. A one-way ANOVA revealed no significant differences among the three groups for any of the variables, although differences in duration of disease approached significance ($p=0.056$). Inspection of the data indicated that the isometric group had the disease longer. The average of these subjects tended to be skewed by the value of one individual who had the disease 23.5 years.

B. CYBEX MEASUREMENTS

The data in this section is presented primarily in graph form. Means and standard deviations of pre- and post-test values and their differences are in a table following each graph. Summary tables from the analysis of variance appear in Appendix J.

A three-way ANOVA (SPSS package) was performed to compare the pre-test/post-test differences in peak torque of the strong and weak legs over groups and speeds. As there were no significant differences between legs, all torque results are presented as the total of both legs. Richards (1980) reported no significant differences in torque between the more affected and the less affected limbs of patients with RA. The data of Nordemar et al (1976a) also indicated no differences in initial isometric torque or changes with training between the two legs.

PEAK TORQUE

Figure 4.1 and table 4.2 show the results for peak torque measurements for all groups. Observation of the data

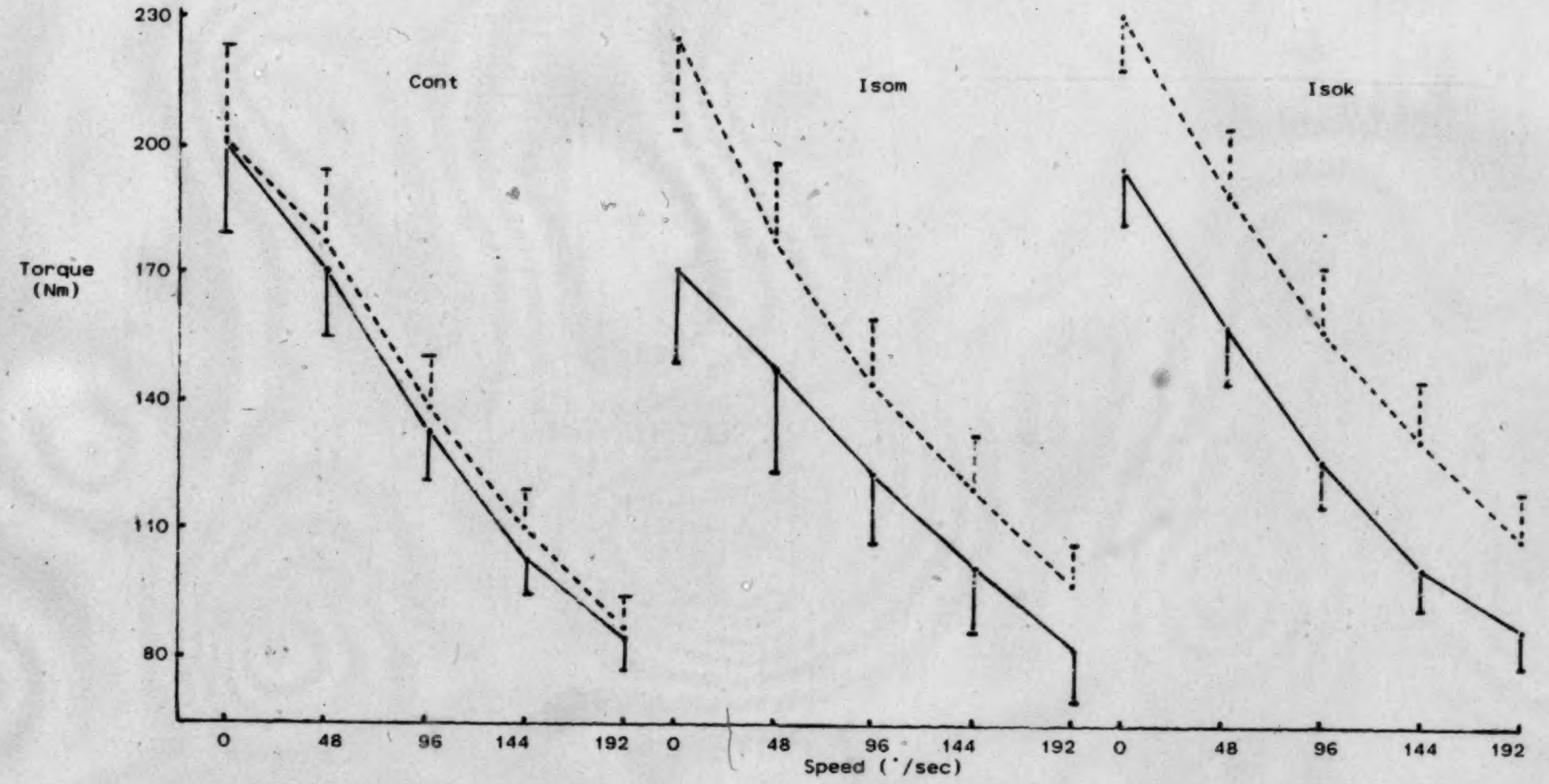

Figure 4.1: Knee extension peak torque - pre- and post-test mean values ± standard error (——pre ---post)

TABLE 4.2

KNEE EXTENSION PEAK TORQUE
Mean±Standard Deviation (Nm)

		SPEED (°/sec)				
GROUP	TIME	0	48	96	144	192
Cont	Pre	202.0	171.2	133.8	103.6	85.0
		±72.5	±49.8	±37.1	±25.8	±21.6
	Post	201.4	177.2	138.1	110.6	87.4
		±71.3	±52.4	±35.5	±27.6	±21.9
	Diff	-0.6	6.0	4.3	7.0	2.4
Isom	Pre	171.5	147.7	123.1	102.5	83.7
		±68.6	±64.5	±53.1	±46.9	±38.0
	Post	226.0	177.6	145.1	120.0	98.2
		±75.8	±56.9	±46.6	±37.8	±29.9
	Diff	[1]54.5	[1,3]29.9	[3]22.0	[3]17.5	[3]14.5
Isok	Pre	195.1	158.8	127.5	102.0	86.7
		±41.0	±41.8	±34.1	±28.4	±28.4
	Post	230.0	189.2	157.5	132.2	109.4
		±46.3	±48.1	±45.6	±40.0	±34.4
	Diff	[1]34.9	[1]30.4	[1]30.0	30.2	22.7

[1] significantly different from control
[2] significantly different from isometric
[3] significantly different from 0°/sec
[4] significantly different from 48°/sec
[5] significantly different from 96°/sec
[6] significantly different from 144°/sec

suggested that the isometric group had lower peak torque values at the beginning of the study than the other two groups. A two-way ANOVA was performed to determine if this difference was statistically significant at any of the speeds. It was not. However, it is always a possibility that the amount of improvement in this group was due to its lower pre-test values. It is well recognized that the degree of response to strength training diminishes as a person reaches his 'limiting strength' (Müller 1972). The difference between the isometric group and the other two groups diminished at the higher velocities. This observation may be related to the muscle pathology, a point that will be discussed later.

The shape of the torque-velocity curves was similar for all groups and resembled that described for normal subjects (Thorstensson et al 1976a, Scudder et al 1980). Richards (1980) also reported that RA subjects had torque-velocity relationships similar to a normal group. She reported peak knee extension torques of 84, 73 and 55 Nm at 30°, 90° and 180°/sec respectively. Considering the difference in test speeds, the pre-test torque values of the patients in this study (half of the two-leg score presented in table 4.2) are similar to those of Richards.

The two-way ANOVA performed on the torque changes indicated significant group and speed main effects and an interaction effect.

For the isometrically trained group, improvement in peak torque at 0°/sec was greater than at all other speeds. There were no statistically significant differences among the faster speeds. The changes in torque with training were equal at all velocities tested for the isokinetic group. There were no statistically significant differences between the exercise groups at any speed. However, the isometric group had a mean improvement in isometric peak torque that was 19.6 Nm greater than the mean value for the isokinetic group. This difference was close to the difference of 20.5 Nm required for significance in the post-hoc analysis, suggesting a tendency for greater changes in the type of contraction that was used for training. Both the isometric and isokinetic subjects had greater improvement than the control subjects at 0° and 48°/sec, and the isokinetic group also was better than the control for 96°/sec.

The results of the present study are similar to those of Thistle et al (1976) who studied normal subjects. Their slow speed group had greater improvement but at the slow speed only, while their high speed group had more uniform results across all velocities tested. Lesmes et al (1978) also reported similar increases in peak torque at 0°, 60°, 120° and 180°/sec after training at the latter speed. Lindh (1979), in a study on normal females, found that isometric training improved isokinetic torque measurements at 30°/sec, but not at 180°/sec.

These studies suggest that isometric or slow speed training will improve muscle torque at slow speeds only, but that the higher velocity training will result in changes at all speeds below the training velocity. The isometric group in the present study followed the pattern expected from the above studies. The isokinetic group, on the other hand, did not show statistically significant improvement at the two velocities closest to its training velocity.

Costill et al (1979) had similar results when training subjects at 180°/sec. They found greater improvement in isometric torque than torque at the training velocity. Perhaps in both this study and that of Costill et al, the subjects had particular muscle characteristics that limited the response at the faster speeds. Dons et al (1979) suggested from the results of their study that a high percentage of FT fibres was a prerequisite for successful strength training. As several authors have reported correlations between FT fibre content or area and performance of muscle at 180°/sec (Komi and Tesch 1979, Nilsson et al 1977, Thorstensson 1976), the content or status of the type II fibres may have even a greater influence on the capacity of a muscle to change its performance at the higher velocities. It is possible that the involvement of type II fibres in rheumatoid muscle may have limited both the initial measurements of torque and the changes in torque at the higher velocities. This point is discussed further with the data on the muscle biopsy.

However, the results also indicate that in spite of the muscle disease, both forms of exercise will lead to increases in peak torque.

TORQUE AT 30°

The results of tests of torque at 30° are presented in figure 4.2 and table 4.3. Again the isometric group had mean pre-test values lower than the other two groups. The shapes of the torque-velocity curves, however, were similar in all three, ie, the slope was less at the lower velocity end of the curve. This shape is similar to that described for knee extension torque at 30° for normal subjects and athletes (Perrine and Edgerton 1978, Gregor et al 1979), but differs from the peak torque curve in this study and that of Thorstensson et al (1976). One possible explanation for the difference in shape at 30° and peak is the fact that peak torque occurs later in the movement (ie, closer to full extension) as speed increases. Therefore, torque at 30° and at peak are closer to the same position and thus the same value at the faster speeds, but further apart in both as the speed approaches 0°/sec.

The post-test torque curves of the two training groups had a shape that more closely resembles that of the peak torque curve. This change in shape was due to significant improvement in torque at the slow speeds for these groups compared to the control group (see table 4.3). There were no significant differences among groups at the other speeds,

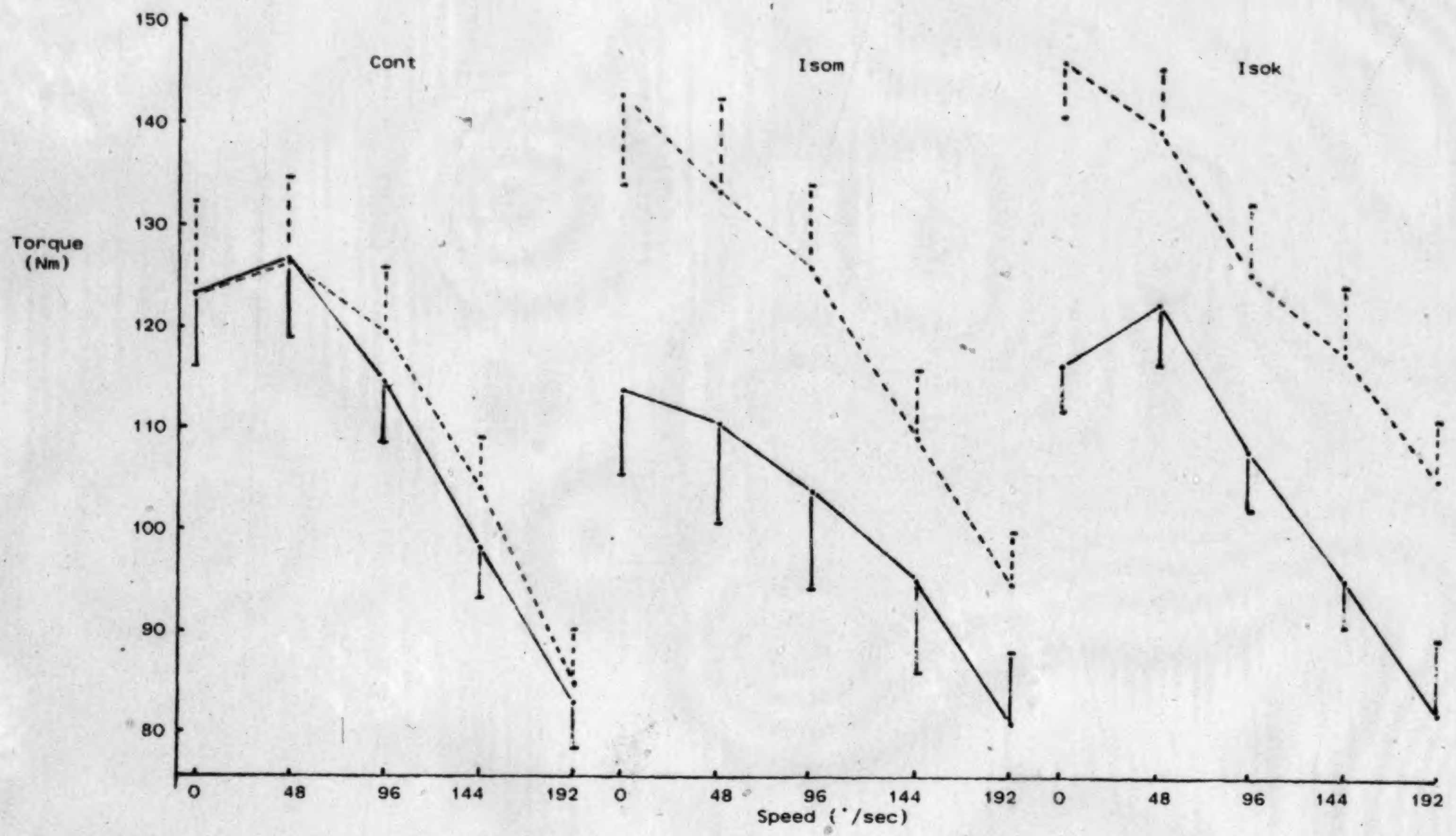

Figure 4.2: Knee extension torque at 30° - pre- and post-test mean values ± standard error (—pre ---post)

TABLE 4.3

KNEE EXTENSION TORQUE AT 30°
Mean±Standard Deviation (Nm)

		SPEED (°/sec)				
GROUP	TIME	0	48	96	144	192
Cont	Pre	123.4	127.3	115.4	98.4	83.0
		±35.0	±38.3	±30.4	±25.4	±22.9
	Post	123.2	126.9	119.8	104.3	85.3
		±43.9	±41.6	±30.4	±26.2	±23.4
	Diff	-0.2	-0.4	4.4	5.9	2.3
Isom	Pre	114.3	111.0	104.3	94.8	81.3
		±41.1	±48.2	±47.2	±45.5	±34.7
	Post	143.2	133.8	126.0	108.9	94.7
		±43.7	±44.0	±41.3	±33.5	±26.8
	Diff	[1]28.9	[1]22.8	21.7	14.1	13.4
Isok	Pre	116.2	121.8	108.0	95.6	82.3
		±23.8	±30.9	±30.8	±24.9	±36.5
	Post	146.1	139.5	125.7	117.4	104.8
		±28.7	±31.3	±35.4	±33.3	±32.1
	Diff	[1]29.9	[1]17.7	17.7	21.8	22.5

[1] significantly different from control
[2] significantly different from isometric
[3] significantly different from 0°/sec
[4] significantly different from 48°/sec
[5] significantly different from 96°/sec
[6] significantly different from 144°/sec

although the difference in improvement between the isokinetic and control groups approached significance at 192°/sec (a real difference of 20.2 Nm versus a required difference of 20.8 Nm).

It is possible that the greater changes at the slow speeds may be due to an increased ability to recruit muscle fibres at the 30° angle following training. Some patients felt they "couldn't get a good push" at 30°, or they felt like they were "reaching". If the theory of DeAndrade et al (1965) is true, inhibition at this angle may be greater in RA patients with knee swelling due to feedback inhibition from joint receptors. Stratford (1982) found that the ratio of EMG of the quadriceps during a maximal contraction at 0° and 30° was less than 1.0 in effused knees, but not in normal knees. He did not, however, measure EMG at greater angles of knee flexion. Richards (1980) reported a greater difference between the EMG of the quadriceps of normal and RA subjects as the knee approached full extension.

The change in the isokinetic group at the faster speed shows a trend towards a specific training effect for this group. The possible roles of recruitment of muscle fibres and/or change in their force production characteristics are discussed in the section on muscle biopsy data.

POWER AT 30°

The shape of the power-velocity curves for all three groups (figure 4.3) can be compared to that of Perrine and

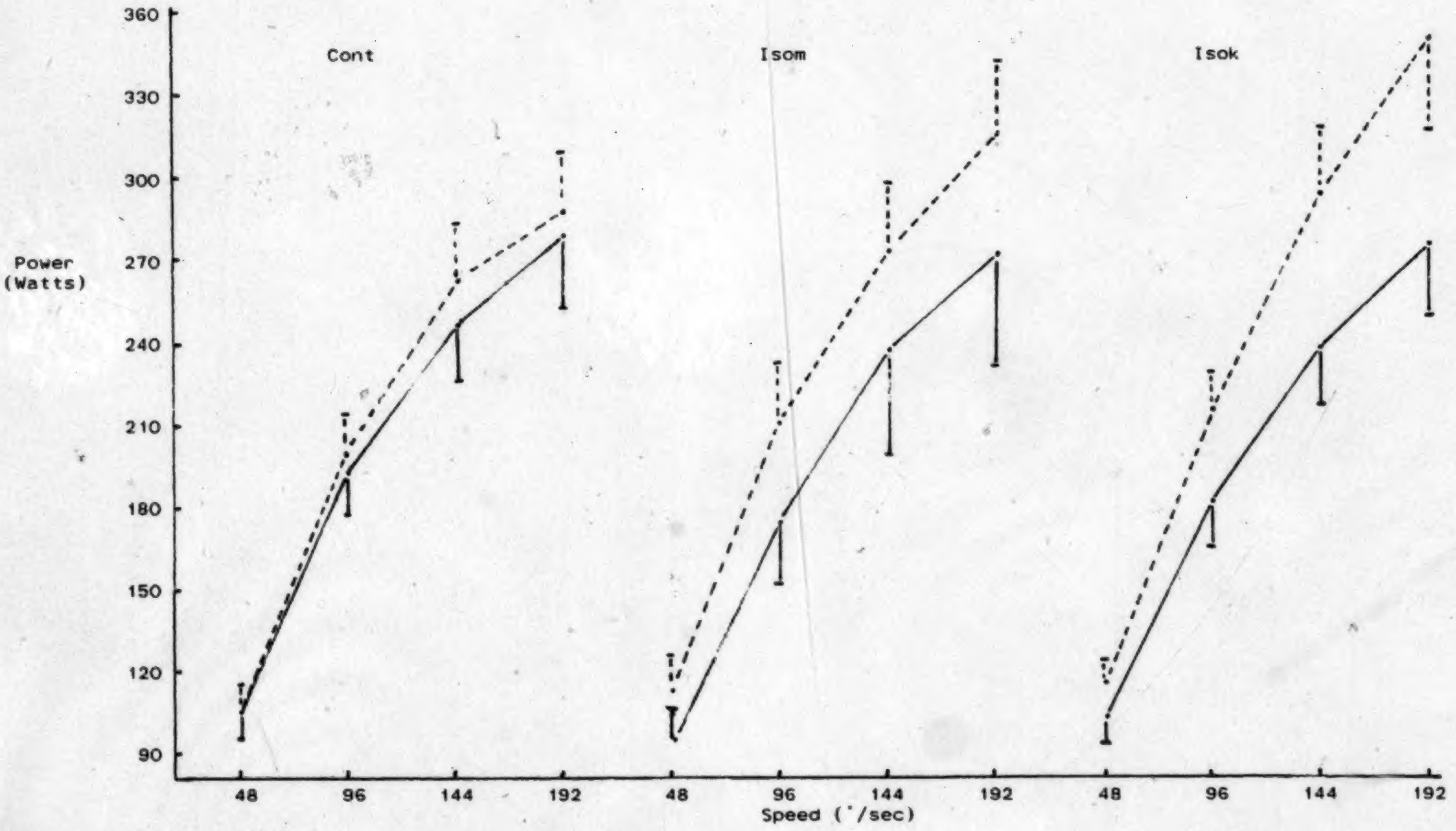

Figure 4.3: Knee extension power at 30° - pre- and post-test mean values ± standard error (—pre ---post)

TABLE 4.4

KNEE EXTENSION POWER AT 30°
Mean±Standard Deviation (Watts)

		SPEED (°/sec)			
GROUP	TIME	48	96	144	192
Cont	Pre	106.9	193.9	247.1	278.1
		±32.1	±50.7	±64.1	±76.8
	Post	106.6	201.4	261.8	285.8
		±34.7	±51.1	±65.7	±78.2
	Diff	-0.3	7.5	14.7	7.7
Isom	Pre	93.4	175.2	237.8	272.3
		±40.5	±79.2	±114.1	±119.7
	Post	112.5	211.6	273.3	317.1
		±36.9	±69.5	±84.2	±88.7
	Diff	19.1	36.4	35.5	44.8
Isok	Pre	102.4	181.5	239.9	275.9
		±26.1	±51.8	±62.7	±79.9
	Post	117.1	211.0	294.7	351.1
		±26.4	±59.4	±83.6	±107.9
	Diff	14.7	29.5	[4,5]54.8	[4,5]75.2

[1] significantly different from control
[2] significantly different from isometric
[3] significantly different from 0°/sec
[4] significantly different from 48°/sec
[5] significantly different from 96°/sec
[6] significantly different from 144°/sec

Edgerton (1978) for normal subjects, although they also tested power at higher velocities (figure 2.2A). Both curves demonstrate increases in power with increased velocity of contraction. However, in normal subjects, the relationship was linear up to 144°/sec. In the RA subjects of this study, the linearity of the curve was only maintained to 96°/sec. Rothstein et al (1981) also reported deviations from normal in the slope of the power-velocity curve at higher velocities in a group of rheumatic disease patients which included persons with RA.

The values obtained for power (half of the two-leg value in table 4.4) are higher than those recorded by Rothstein et al (1981) for rheumatic disease patients. Their subjects were all on steroids, and included patients without RA. In addition, they did not state their method of calculating power. On analysis of the change between pre- and post-test scores, there were no statistically significant differences among groups (p=0.06), but there were among speeds. Improvement in power was greater at the two faster velocities than at the two lower ones for the isokinetically trained group only. In relation to the findings for torque at 30°, the results for power are not surprising, as they are a multiple of the former values. However, the findings indicate that power improvements are greater at the higher speeds for rheumatoids receiving "power" training. The result was a change in the post-test power-velocity relationship to produce a curve similar to that of normal subjects.

WORK DERIVED FROM WHOLE TORQUE CURVE

The findings from measurement of work from the area of the entire torque curve are illustrated in figure 4.4 and table 4.5. The pre/post differences of the isokinetic group were significantly different from the control at all speeds, but not significantly different from the isometric group. The improvement of the isometric group was significantly greater than that of the control group only at 96°/sec. These results again indicate a particular response to each kind of training. The isometric group improved in peak torque at this same speed and the improvement in torque would contribute to an improvement in work. In a similar manner, the changes in work for the isokinetic group are associated with improvement in peak torque at 48° and 96°/sec. However, the isokinetic group had improvements in total work at the higher speeds as well in spite of no significant changes in the torques at these velocities. The isometric group had a change in peak torque at 48°/sec without an accompanying significant change in work.

A possible explanation is a change in the width of the torque curve either at the beginning or at the end of the movement. If the increase is at the beginning, it suggests that training may enable the subjects to produce "recordable" torque sooner in the movement. The effect of this would be greater at the faster speeds where there is often a lag until the patient's movement has reached the

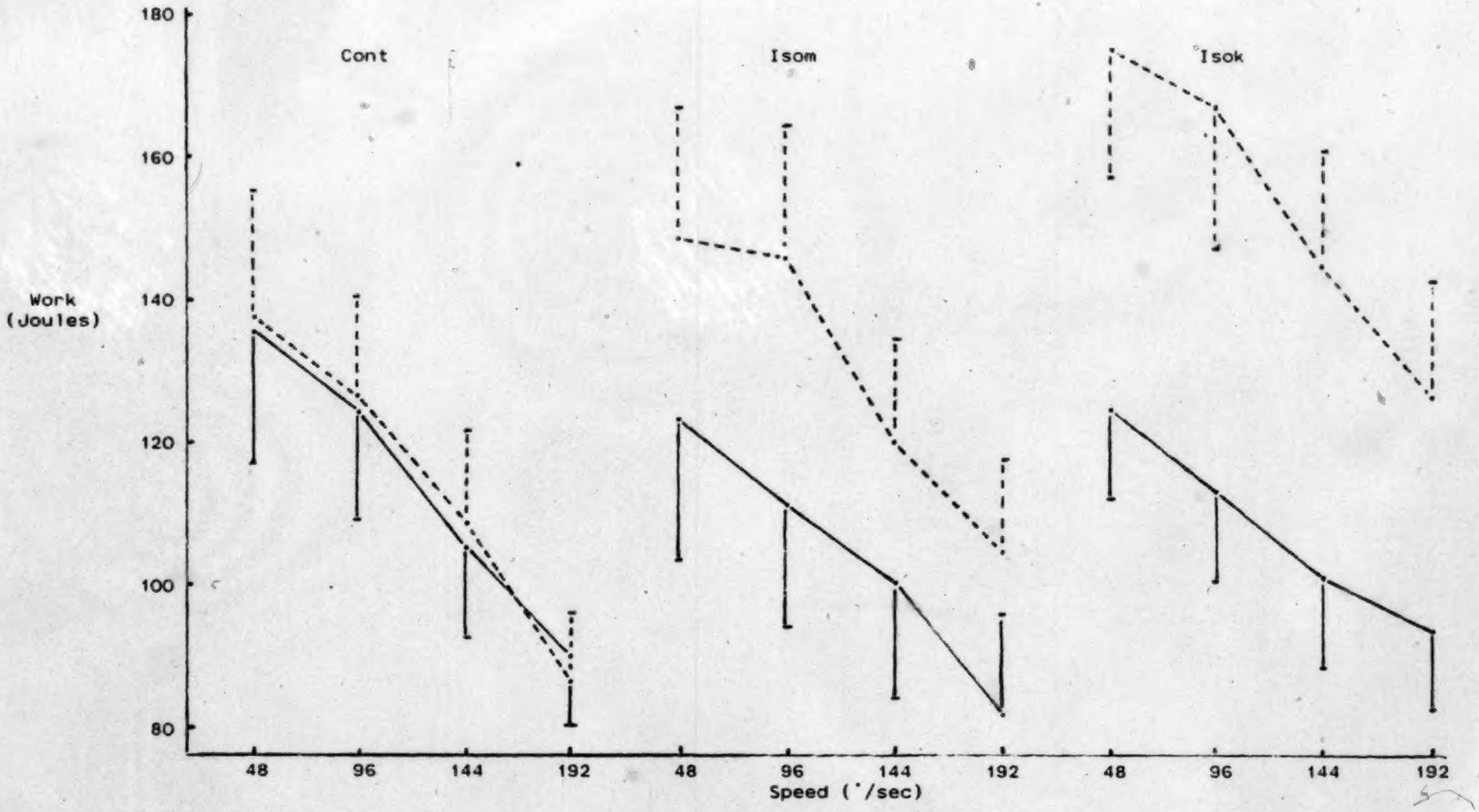

Figure 4.4: Work of knee extension (total) - pre- and post-test mean values ± standard error (—pre ---post)

TABLE 4.5

WORK DERIVED FROM WHOLE TORQUE CURVE
Mean±Standard Deviation (Joules)

		SPEED (°/sec)			
GROUP	TIME	48	96	144	192
Cont	Pre	136.3	125.7	105.8	90.5
		±59.5	±49.8	±40.0	±30.8
	Post	138.0	127.2	108.5	86.5
		±54.6	±44.0	±37.3	±28.7
	Diff	1.7	1.5	2.7	-4.0
Isom	Pre	123.6	112.0	100.2	82.3
		±62.8	±54.0	±52.3	±45.3
	Post	148.3	146.3	121.0	105.0
		±57.5	±57.5	±43.4	±39.9
	Diff	24.7	[1]34.3	20.8	22.7
Isok	Pre	125.3	113.6	101.4	94.1
		±42.0	±43.9	±42.1	±48.9
	Post	175.2	166.9	144.8	126.7
		±59.4	±65.1	±53.7	±52.1
	Diff	[1]49.9	[1] 53.3	[1]43.4	[1,4,5]32.6

[1] significantly different from control
[2] significantly different from isometric
[3] significantly different from 0°/sec
[4] significantly different from 48°/sec
[5] significantly different from 96°/sec
[6] significantly different from 144°/sec

speed of the dynamometer. Changes in the width of the torque curve on the right indicate that subjects are maintaining torque output into full extension of the knee. Again, due to the follow through of the leg, the effect of this would be greater at the faster speeds and probably greater in the isokinetic subjects who were used to kicking the leg through a range of movement.

Perhaps, though, changes in torque have the greatest influence on changes in work as the latter was greater for the isokinetic group at the two slower speeds than at 192°/sec.

WORK BETWEEN 75° AND 15°

Differences in the changes in work measured between 75° and 15° (figure 4.5, table 4.6) were statistically significant among groups only (p=0.046). At speeds of 96°/sec and 144°/sec, the improvement in the isokinetic group was significantly greater than the control group but not the other training group. The changes in this measurement depict increases in torque output over a particular range while the previous work measurement also included changes in work due to producing torque through a greater range. However, again at the faster speeds, it is possible that improvement in work is also due to an improved ability to accelerate the leg to the testing velocity. A number of subjects both pre-test and post-test were unable to produce a torque recording by the first 15° of movement

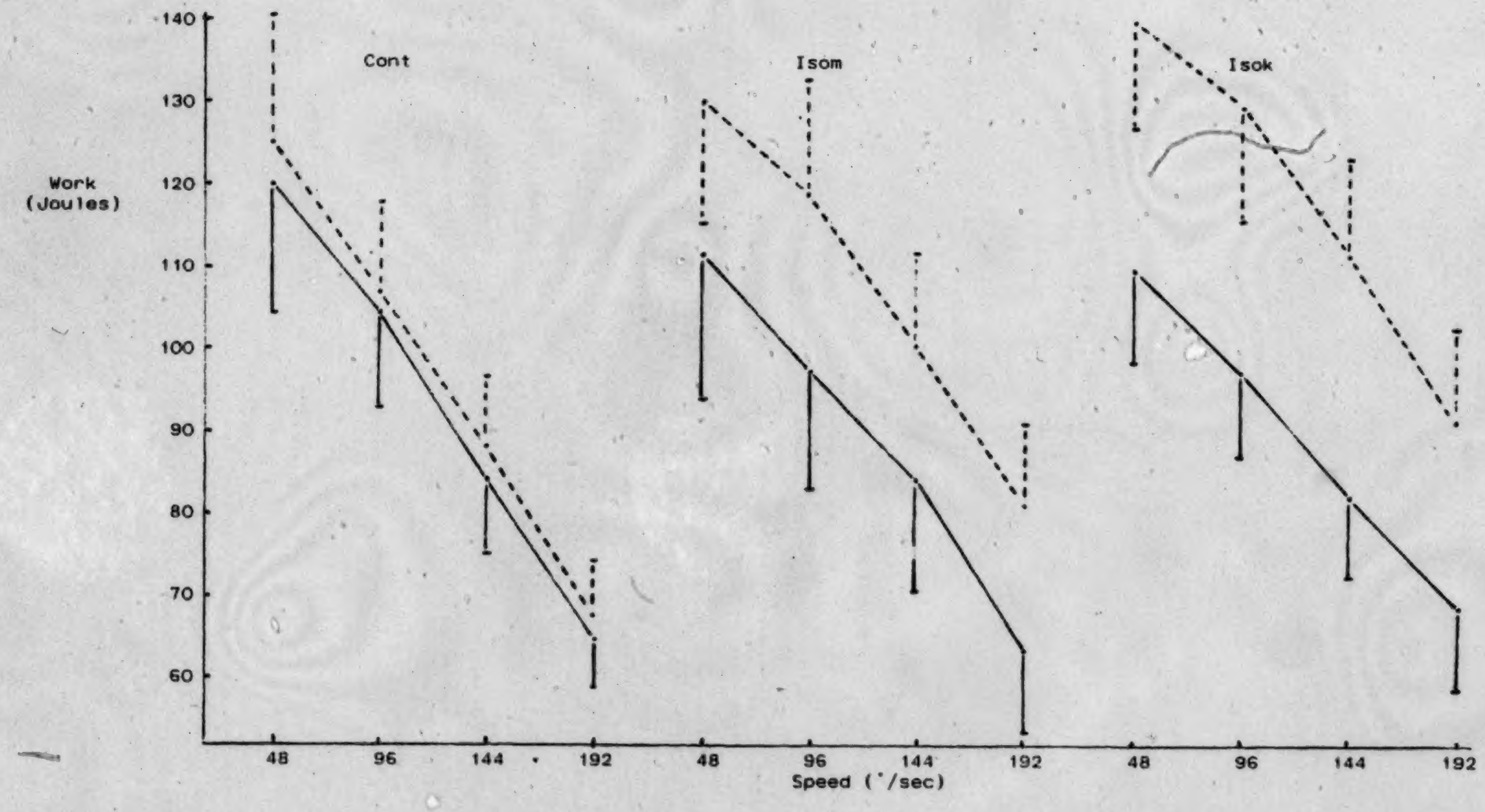

Figure 4.5: Work of knee extension between 75° and 15° - pre- and post-test mean values ± standard error (—pre ---post)

TABLE 4.6

WORK BETWEEN 75° AND 15°
Mean±Standard Deviation (Joules)

		SPEED (°/sec)			
GROUP	TIME	48	96	144	192
Cont	Pre	120.3	105.2	84.6	66.2
		±48.1	±36.9	±28.5	±19.8
	Post	125.0	107.5	87.6	67.8
		±45.7	±33.8	±27.8	±20.4
	Diff	4.7	2.3	3.0	1.6
Isom	Pre	111.5	97.8	84.2	63.4
		±54.3	±44.8	±41.1	±32.5
	Post	130.1	119.2	100.1	81.9
		±45.5	±42.4	±34.7	±29.9
	Diff	18.6	21.4	15.9	18.5
Isok	Pre	110.4	97.3	82.2	68.8
		±36.9	±33.4	±31.2	±32.7
	Post	139.9	129.8	111.8	91.3
		±41.9	±43.4	±37.2	±34.6
	Diff	29.5	[1]32.5	[1]29.6	22.5

[1] significantly different from control
[2] significantly different from isometric
[3] significantly different from 0°/sec
[4] significantly different from 48°/sec
[5] significantly different from 96°/sec
[6] significantly different from 144°/sec

at the higher speeds.

Because the isokinetic group trained by producing work (ie, producing torque through a range of movement), it would seem reasonable that the subjects would fair better in this test.

POWER DERIVED FROM WHOLE TORQUE CURVE

The two-way ANOVA of changes in power derived from the whole torque curve revealed statistically significant group and velocity effects and an interaction effect. At speeds of 96° and 192°/sec, both training groups had significantly greater improvement in power derived from the whole torque curve than the control group (figure 4.6, table 4.7). The isokinetic group also had greater changes at 144°/sec. There were no statistically significant differences among speeds for the isometric group, but for the isokinetic group, improvement was greater at the three higher speeds than at 48°/sec. The latter results indicate again a tendency toward a specific training effect for the isokinetic group with greater improvements in power closer to the speed at which they trained.

POWER BETWEEN 75° and 15°

The results on power between 75° and 15° are presented in figure 4.7 and table 4.8. Again the shape of the curves are similar to those seen in the other power measurements, with a decrease in the slope at higher velocities, but a

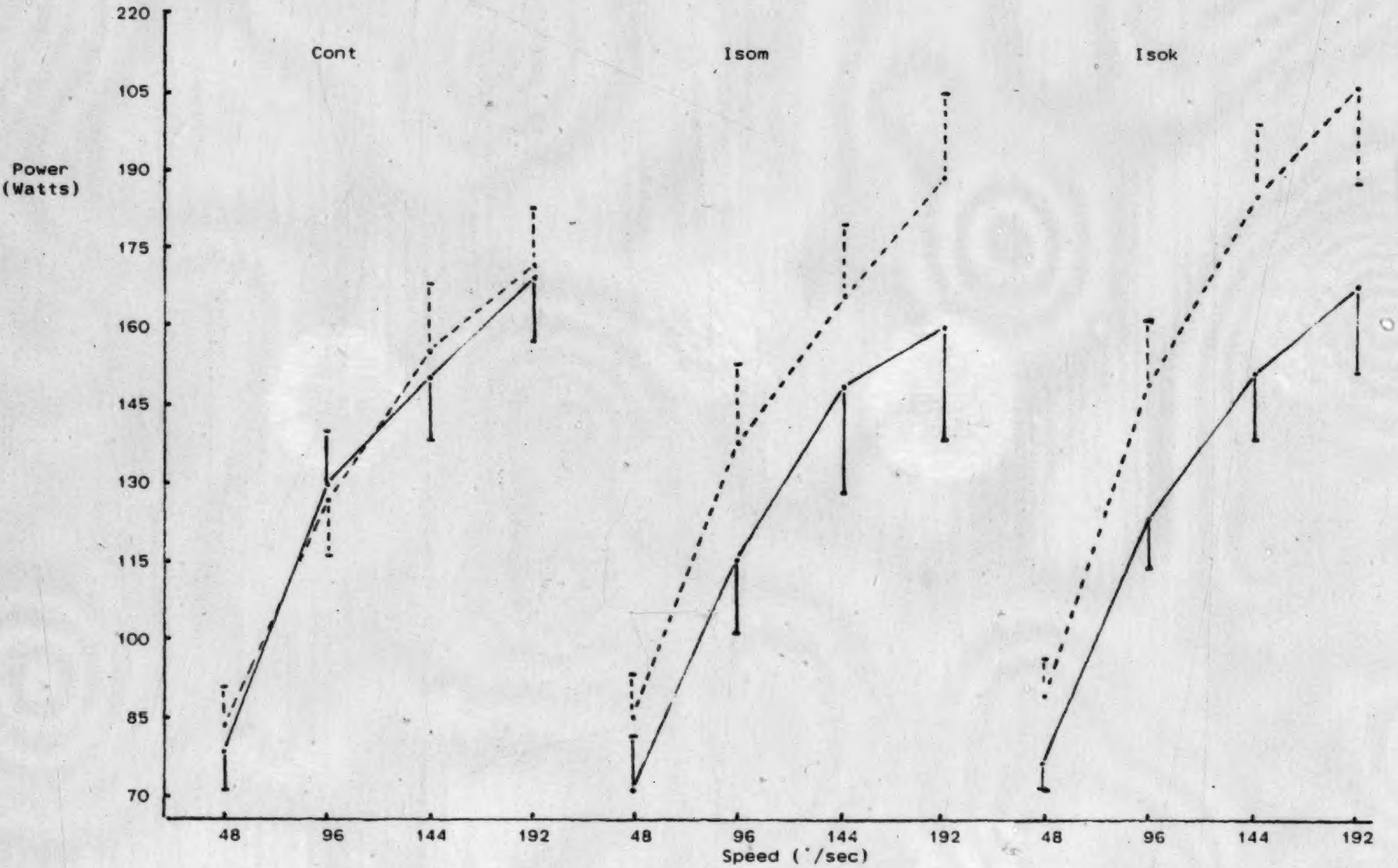

Figure 4.6: Knee extension power (total) - pre- and post-test mean values ± standard error (——pre ---post)

TABLE 4.7

POWER DERIVED FROM WHOLE TORQUE CURVE
Mean±Standard Deviation (Watts)

		SPEED (°/sec)			
GROUP	TIME	48	96	144	192
Cont	Pre	78.7	130.5	151.3	169.4
		±21.6	±32.1	±38.5	±38.8
	Post	84.3	127.4	156.8	171.4
		±24.0	±33.8	±40.4	±36.9
	Diff	5.6	-3.1	5.5	2.0
Isom	Pre	71.7	116.7	148.5	160.6
		±32.4	±46.4	±65.2	±68.6
	Post	85.3	139.1	166.9	189.2
		±26.9	±47.2	±44.5	±53.8
	Diff	13.6	[1]22.4	18.4	[1]28.6
Isok	Pre	77.2	123.7	150.4	167.1
		±18.3	±30.7	±42.4	±56.0
	Post	89.7	149.2	183.3	206.0
		±23.4	±43.0	±49.6	±58.8
	Diff	12.5	[1,4]25.5	[1,4]32.9	[1,4]38.9

[1] significantly different from control
[2] significantly different from isometric
[3] significantly different from 0°/sec
[4] significantly different from 48°/sec
[5] significantly different from 96°/sec
[6] significantly different from 144°/sec

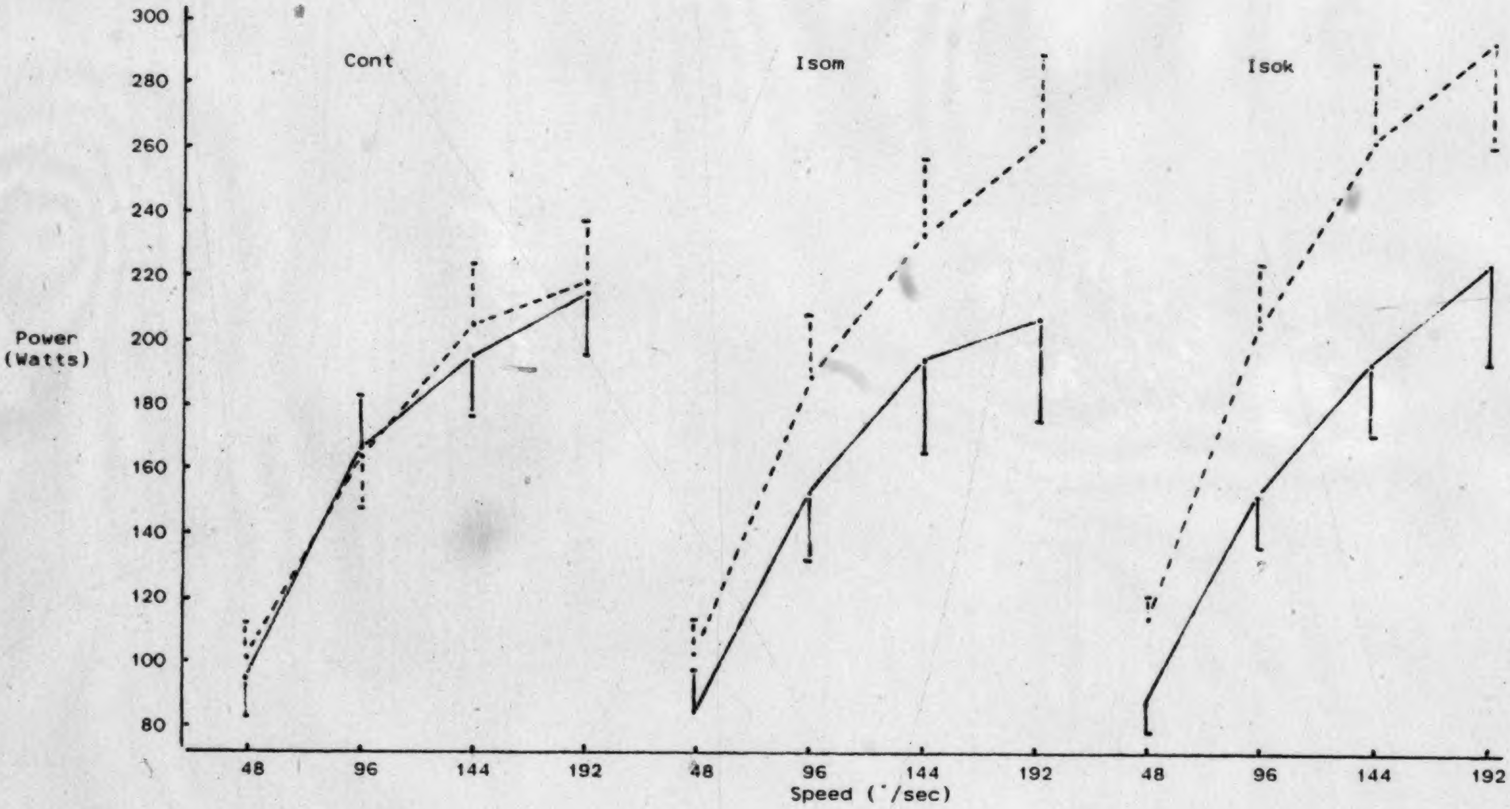

Figure 4.7: Knee extension power between 75° and 15° - pre- and post-test mean values ± standard error (——pre ---post)

TABLE 4.8

POWER BETWEEN 75° AND 15°
Mean±Standard Deviation (Watts)

		SPEED (°/sec)			
GROUP	TIME	48	96	144	192
Cont	Pre	95.9	165.8	196.1	214.6
		±38.2	±57.8	±65.6	±64.3
	Post	101.6	164.8	205.8	215.7
		±36.9	±55.5	±65.5	±68.0
	Diff	5.7	-1.0	8.9	1.1
Isom	Pre	86.7	154.2	195.6	207.1
		±42.0	±70.5	±95.3	±106.5
	Post	103.5	188.5	232.4	261.8
		±35.9	±66.6	±80.4	±93.8
	Diff	16.8	34.3	36.8	[4]54.7
Isok	Pre	88.0	153.1	192.5	223.5
		±29.1	±53.0	±74.1	±107.3
	Post	111.1	203.9	261.4	293.5
		±33.0	±68.1	±87.9	±113.5
	Diff	23.1	[1,4]50.8	[1]68.9	[1,4]70.0

[1] significantly different from control
[2] significantly different from isometric
[3] significantly different from 0°/sec
[4] significantly different from 48°/sec
[5] significantly different from 96°/sec
[6] significantly different from 144°/sec

change towards a more normal power-velocity relationship after training. The values of power are higher than those derived from the whole torque curve, but lower than power calculated from torque at 30°.

As with the previous power measurement, the ANOVA showed significant group and speed effects on pre/post differences. Post-hoc analysis showed that at speeds from 96°/sec to 192°/sec, the isokinetic group improved in power measurements over the control group. At 192°/sec, the improvement of the isometric group was also greater than the control. For both training groups, improvement at 192°/sec was greater than at 48°/sec, and for the isokinetic group, improvement at 144°/sec was also greater than at the slowest speed. The greater changes in the higher speeds are due to a greater multiplication factor used for calculating power at these speeds. With similar changes in peak torque at the various velocities (isokinetic group), improvement in power would increase with increasing velocities. Even with smaller changes in torque at the higher speeds (isometric group), changes in power at these speeds can be greater. In addition, any errors in measurement of the area of the torque curve are magnified in the calculation of power at the higher speeds.

ISOMETRIC TORQUE AT 30°, 60° AND 90°

General observation of the isometric torque-angle curves (figure 4.8, table 4.9) indicates that the

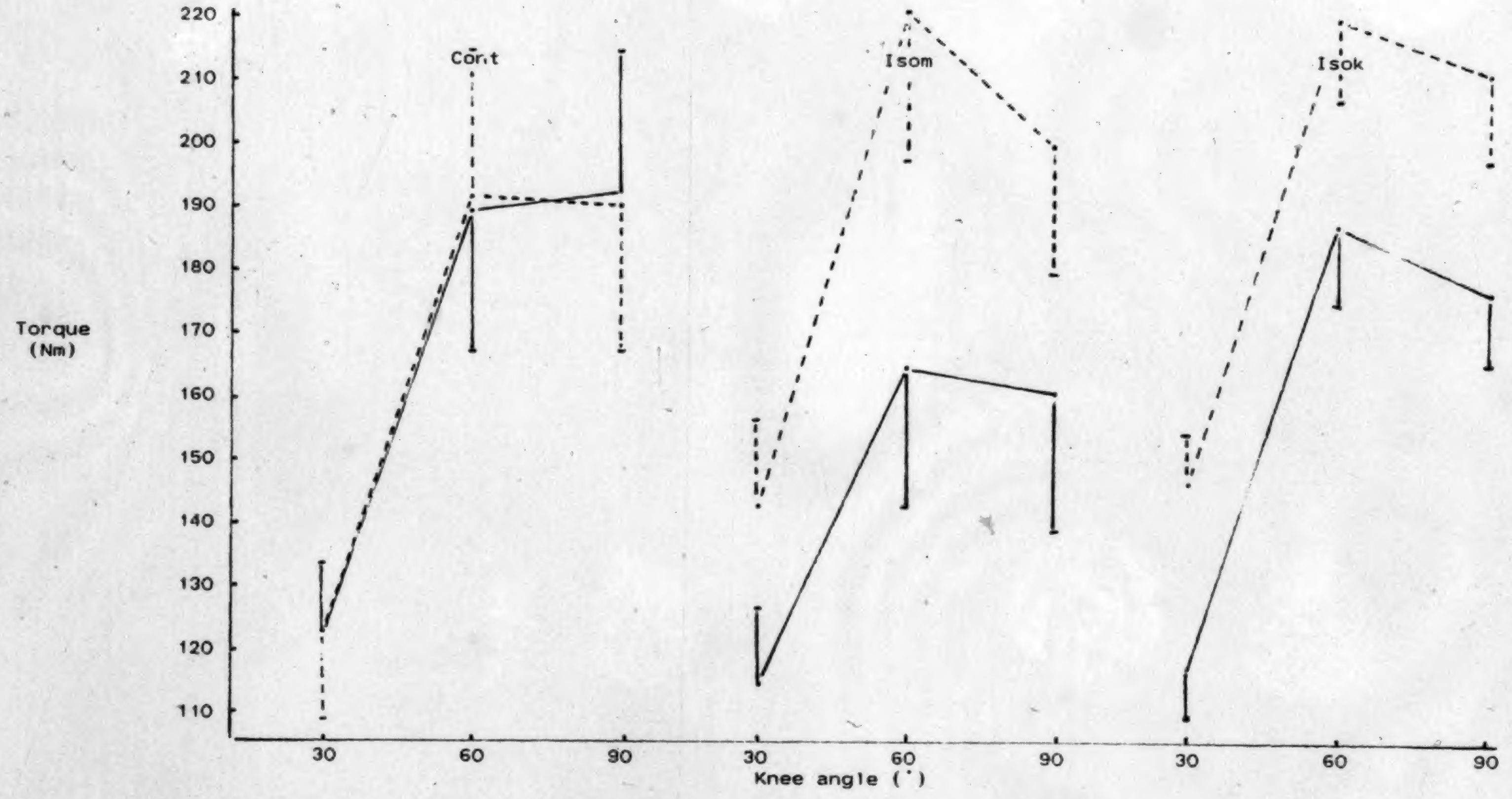

Figure 4.8: Isometric torque at 30˚, 60˚, and 90˚ - pre- and post-test mean values ± standard error (—pre ---post)

TABLE 4.9

ISOMETRIC TORQUE AT 30°, 60° AND 90°
Mean±Standard Deviation (Nm)

		ANGLE (°)		
GROUP	TIME	30	60	90
Cont	Pre	123.4	[3]189.9	192.5
		±35.0	±71.2	±69.8
	Post	123.2	[3]192.0	190.8
		±43.9	±70.5	±71.8
	Diff	-0.2	3.9	-1.7
Isom	Pre	114.3	[3]165.1	161.1
		±41.1	±68.2	±68.8
	Post	143.2	[3]222.3	200.4
		±43.7	±74.7	±62.5
	Diff	[1]28.9	[1]57.2	[1]39.3
Isok	Pre	116.2	[3]187.5	177.5
		±23.8	±40.4	±41.6
	Post	146.1	[3]218.9	211.3
		±28.7	±43.5	±47.0
	Diff	[1]29.9	[1,2]31.4	[1]33.8

[1] significantly different from control
[2] significantly different from isometric
[3] significantly different from 30°
[4] significantly different from 60°

relationship of torque and angle in the knee extensors is much the same in rheumatoid and normal subjects (Clarke et al 1950, Williams and Stutzman 1959, Scudder 1980). A three-way ANOVA (group vs time vs angle) demonstrated a statistically significant difference between the scores at 60° and 30°, but not between 60° and 90° for all groups pre- and post-test. There were no statistically significant differences among groups for torque measurements prior to training, although figure 4.8 suggests that the isometric group had lower initial values. A similar tendency was observed for peak torque and torque at 30°. Changes in isometric torque were greater in both training groups compared to the control for the three angles tested. At the 60° angle, the change in the isometric group was also greater than in the isokinetic group. Although this result could be interpreted as specificity of training, the better response of the isometric group may be partly due to their lower pre-test scores.

There were no statistically significant differences in training response among angles (p=0.073). However, post-hoc analysis indicated that for the isometric group, improvement at 60° was greater than at the other two angles. This could signify a ceiling effect, ie, at a joint angle of 30° and 90°, improvement in the quadriceps output may be limited by the moment arm and length-tension characteristics of the muscle.

RELATIONSHIP OF CYBEX MEASUREMENTS

Pearson product moment correlations were performed on a number of scores derived from the Cybex and on their pre/post differences.

Analysis of pre-test data demonstrated highly significant correlations between all measurements of work and power at each of the four test velocities. Similar results were found when comparing the isometric torque at three angles both before and after training. Selected correlation coefficients are presented in table 4.10.

Others have found significant correlations between torque and work measurements in normal individuals (Richards 1980, Nilsson et al 1977, Moffroid and Kusiak 1975).

Correlations of the pre/post differences of torque scores at the various velocities are presented in table 4.11. The majority of scores were significantly correlated. However, changes in isometric torque scores were not related to changes at the higher speeds. The lack of correlation may be due in part to the different responses of the three groups to their specific training. However, the results also imply differences in mechanisms of strength improvement at fast and slow speeds. This is discussed further with the muscle biopsy data.

Correlations between torque changes at 30° and peak torque were statistically significant at all velocities - .833, .589, .735, .947, .959 for 0°, 48°, 96°, 144°, and 192°/sec respectively. The finding of higher correlations at

TABLE 4.10

CORRELATIONS OF PRE AND/OR POST CYBEX MEASUREMENTS

ISOMETRIC SCORES

TIME		Pre			Post	
	Angle	30°	60°	90°	30°	60°
Pre	60°	.933				
	90°	.838	.926			
Post	30°	.777				
	60°		.812		.917	
	90°			.863	.764	.873

CORRELATIONS OF PRE-TEST POWER AND/OR WORK MEASUREMENTS

	VELOCITY (°/sec)			
COMPARISON	48	96	144	192
Power 30°/total	.910	.950	.980	.976
Power 30°/(75°-15°)	.910	.930	.952	.931
Power total/(75°-15°)	.971	.970	.978	.964
Work total/(75°-15°)	.991	.985	.968	.958

all values are significant (p≤.05)

TABLE 4.11

CORRELATIONS OF TORQUE CHANGES AT DIFFERENT VELOCITIES

PEAK TORQUE

VELOCITY	0°/sec	48°/sec	96°/sec	144°/sec
48°/sec	.453			
96°/sec	.400	.864		
144°/sec	.347	.806	.920	

192°/sec	.193	.730	.814	.864

TORQUE AT 30°

VELOCITY	0°/sec	48°/sec	96°/sec	144°/sec
48°/sec	.675			
96°/sec	.559	.690		
144°/sec	.257	.443	.793	
192°/sec	.247	.468	.687	.855

the higher speeds is in agreement with the differences in the shape of the torque-velocity curves for 30° and peak at the lower speeds and the suggestion that the two torque measurements are closer in value at the higher speeds.

SUMMARY OF TORQUE RESULTS

The findings from the torque curve measurements indicate that patients with rheumatoid arthritis can improve the torque, work and power output of their muscles with training. The training to some extent has a specific effect, with the isometric group having greatest changes in their training contractions, and the isokinetic group more often having significant improvement in work and power measurements. However, the lower initial values of the isometric group may have contributed to their improvement as their post-test scores were similar to the isokinetic training group. The lack of statistically significant changes in torque at the higher speeds may be related to the rheumatoid muscle pathology. On the other hand, the results suggest a different mechanism of change required for improvement at fast and slow speeds. An increase in recruitment of fibres is probably an early response to training, whereas changes in protein synthesis and therefore fibre size may require more time or a different form of training.

It should also be noted that differences that were not statistically significant in this study might have been if the number of subjects had been greater. For example, assuming a similar mean value and standard deviation for changes in peak torque, having 20 subjects per group would have produced significant improvement in both exercise groups compared to the control at all speeds, with the exception of the isometric group at the two highest velocities. A study sample of 35 subjects per group would have provided significant differences at all velocities.

C. MUSCLE FIBRE AREA

The pre- and post-test fibre areas for all groups are listed in table 4.12. There were no significant differences in fibre areas at the pre-test nor in the changes of the fibre size with training in the three groups. However, the data indicate some trends - a decrease in fibre area for the control group, a greater increase in ST fibre area for the isometric group and a greater increase in FT fibre area in the isokinetic group. When two persons with the most extreme

TABLE 4.12

MUSCLE FIBRE AREA
Pre- and Post-test Mean Values (U^2)

	FT			ST		
GROUP	Pre	Post	Diff	Pre	Post	Diff
Cont	1667	1393	-274	2241	2020	-221
Isom	1450	1588	138	2409	2703	294
Isok	1859	2121	262	2545	2741	196

[1] significantly different from pre-test value
[2] significantly different from control group
[3] significantly different from isometric group

changes in their fibre size were removed from the analysis (one in the control group, one in the isokinetic group), the trends were similar and the difference among groups approached significance (p=0.08).

In all subjects, the fast twitch fibres were smaller, and in some cases a great deal smaller, than the slow twitch fibres. This finding is similar to others investigating stage I and II RA (Edström and Nordemar 1974, Brooke and Kaplan 1972). The size of fibres was smaller than found by Nordemar et al (1976b) who reported pre-training values of 3290 U^2 and 2890 U^2 for ST and FT fibres respectively.

The fact that there were no changes in fibre size is in contrast to the results of Nordemar et al (1976a). However, the authors did not compare the results of the training group to those of a control group. As well their patients were in hospital during the training period and received other forms of exercise besides strengthening for approximately two hours per day. It is known that a stay in hospital will result in a decrease in disease activity of the joints (Smith and Polley 1978). Perhaps a similar change could occur in the muscles.

On review of the data of Nordemar et al (1976a) presented on individual RA subjects, quite a variation in change in fibre area was noted. A t-test for dependent samples was performed on the data and no significant differences were found between the changes in the FT and ST fibres. Nordemar et al (1976a) had reported a 35% increase in the area of FT fibres and a 23% increase in that of ST fibres. Large variations in change in fibre area were also noted in the present study but they occurred in the control subjects as well. As the muscle disease in RA has been described as "nodular", it may be that with a biopsy, one sample could contain a large number of atrophied fibres, and another sample a larger number of normal sized fibres. The other possibility is that the changes seen in individuals' fibre size may reflect progression or suppression of their muscle pathology. Pearson product moment correlations were performed on the changes in fibre size and torque to shed more light on this theory. The results are presented at the end of this chapter.

Nordemar et al (1976a) found their changes with only 6 weeks of training, but the intensity of their training program was not described. Other studies on normal subjects (MacDougall et al 1977 &1980a) have used five months of training to report changes in muscle fibre size. Therefore it is possible that if the intensity and/or duration of the strength training was increased more definitive changes would have been observed.

D. MEASUREMENT OF DISEASE ACTIVITY

There were no statistically significant differences between pre- and post-test values for any of the disease activity measurements (table 4.13), indicating that the disease activity did not change in any of the three groups over the duration of the study. Therefore, changes in disease status should not be responsible for any differences in torque, muscle fibres, pain or function seen in this study. The results on disease activity indicate also that exercise programs of the intensity and duration of the ones used in this study will not increase the activity of the disease. Similar results have been found with other exercise programs for RA (Ekblom et al 1975a & b, Nordemar et al 1976a & b). Nordemar et al (1981) have also suggested from long term follow-up of persons with RA, that regular exercise may retard the progression of the joint disease.

E. PAIN AND FUNCTION SCALES

FUNCTION SCALE

Comparison of pre- and post-test function scores in the three groups is illustrated in table 4.14. There were significant differences among groups but this was evident at

TABLE 4.13

MEASUREMENTS OF DISEASE ACTIVITY
Pre- and Post-test Mean Values

MEASUREMENT	GROUP	TIME	
		Pre	Post
Grip Strength (mm Hg)	Cont	458	466
	Isom	366	383
	Isok	470	503
Morning Stiffness (min)	Cont	50	22
	Isom	48	67
	Isok	34	30
Fatigue (hrs)	Cont	9.8	9.9
	Isom	8.2	8.0
	Isok	9.2	9.7
Painful Joints (number)	Cont	11.0	12.1
	Isom	14.1	14.3
	Isok	8.5	8.6
Swollen Joints (number)	Cont	7.8	7.4
	Isom	7.0	6.0
	Isok	6.6	7.0

the pre-test, with the isokinetic group having a higher functional score than the isometric group. In addition, the isometric group did not have an increase in their score post-test as did the other two groups.

The isometric group also had lower initial extension torques and FT fibre area than the other groups although these differences were not statistically significant. There

TABLE 4.14

FUNCTION
Pre- and Post-test Mean Values

GROUP	PRE	POST
Cont	79.9	[1]83.1
Isom	72.8	74.9
Isok	[3]88.1	[1,3]91.4

[1] significantly different from pre-test
[2] significantly different from control
[3] significantly different from isometric

may be some subtle differences between the two exercise groups, differences that were present prior to the beginning of the training. From the changes in torque at slow speed, it would appear that the lower initial values have resulted in a greater training effect for the isometric group. However, a failure to improve in function score does not support this hypothesis unless improvement in isometric and slow speed torque will not affect functional activities.

An improvement in function score in the control group might indicate some change in their disease status over the duration of the study. However, they did not change in disease activity or torque measurements. It may be the nature of evaluating function through a questionnaire that leads to improvements with repeated tests. Measurement of specific activities such as stair climbing or walking would have provided more objective data, and perhaps provided different results.

PAIN RATING INDEX

The pain rating index was used on 28 subjects as three patients, all from the isokinetic group, did not have adequate command of English to answer the questionnaire.

The pre- and post-test scores are presented in table 4.15. Only in the isokinetic group was there a statistically significant pre/post difference. This may be in part related to the fact that they experienced less pain during the training sessions than the isometric group. The data on the latter is presented in the next section.

The mean score for the pain rating index was slightly higher than the value (18.8) reported by Melzack (1975). He did not describe the type or severity of the arthritis of his patients.

F. PAIN AND SWELLING DURING EXERCISE

KNEE SWELLING

Changes in circumference of the knee following exercise were not clinically significant, ie, the differences were within the possible error of measurement. Therefore, no further analysis was performed on this data, and it was concluded that the amount of exercise performed in this study did not affect swelling in either exercise group. However, it is possible that a more sensitive method of measuring joint inflammation or heat (Rajapakse et al 1981, Porter et al 1970) might indicate some change with exercise. Porter et al (1970) demonstrated that the clinically normal

TABLE 4.15

PAIN RATING INDEX
Pre- and Post-test Mean Values

GROUP	PRE	POST
Cont	22.3	19.1
Isom	27.3	24.8
Isok	23.6	[1]18.1

[1] significantly different from pre-test
[2] significantly different from control
[3] significantly different from isometric

rheumatoid knee may still show changes in synovial perfursion. Agudelo et al (1972), in their study on crystal-induced experimental arthritis with dogs, found increases in the amount of synovial fluid and the number of white blood cells (WBC) in the fluid following periodic exercise over four hours. The difficulties with comparison with this study are obvious.

EXERCISE PAIN

Figure 4.9 shows the average of the pain experienced during exercise for both experimental groups over three time periods. The Borg scale by its nature produces higher values than the analogue scale. However, the scales are highly correlated; r=0.958, 0.952, and 0.976 for periods 1, 2 and 3 respectively.

The pain experienced by the isometric group was significantly higher than that experienced by the isokinetic group. This finding suggests that the force exerted by the

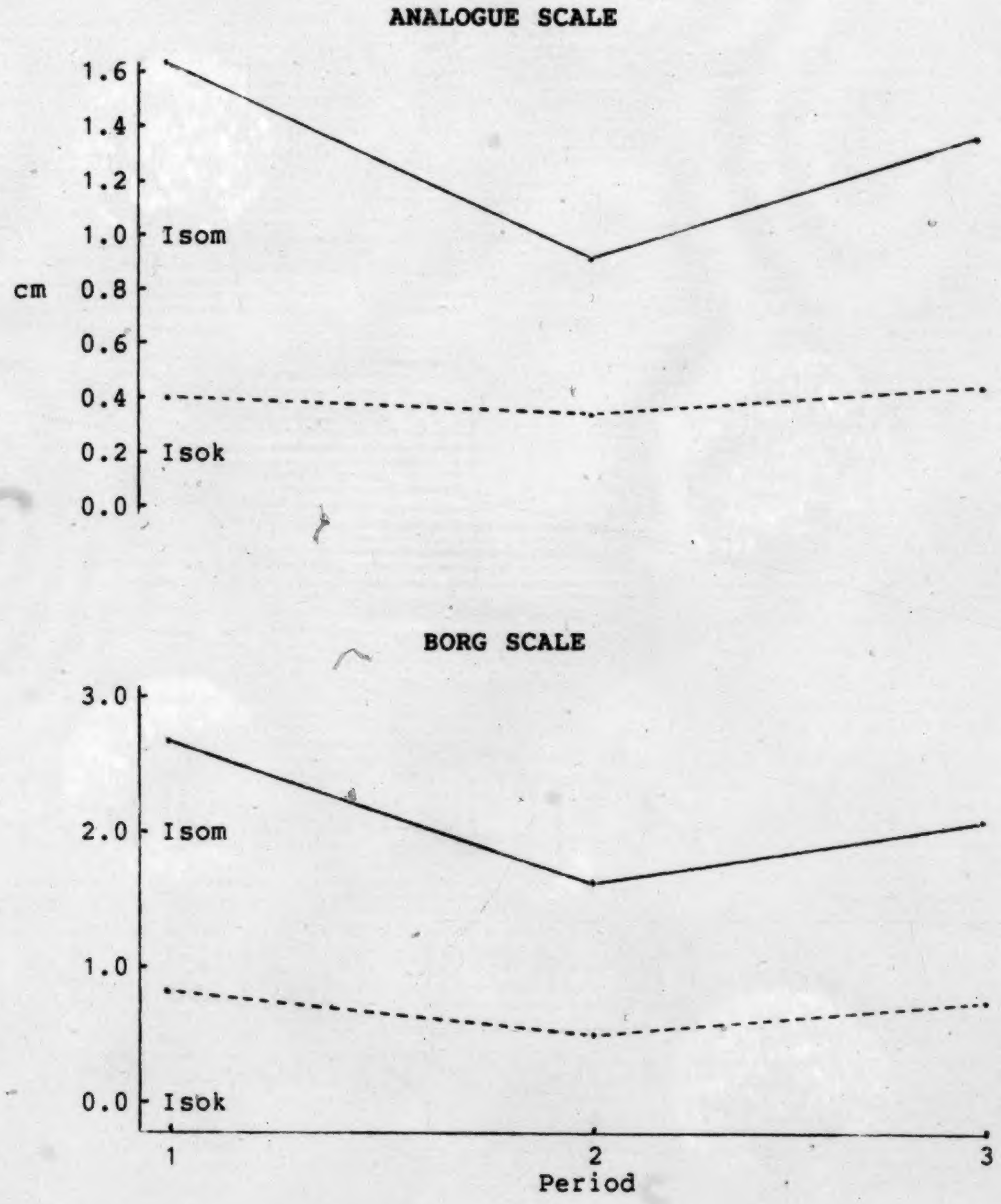

Figure 4.9: Pain experienced during exercise sessions

muscle and thus the force produced at the knee joint, is a more important factor contributing to pain, than the movement of the joint. Thistle et al (1967) reported that isokinetic exercise may produce less pain than isometric or isotonic exercise both in patients and normal subjects. The subjects in that study did not include those with RA or other joint problems.

Machover and Sapechy (1966) also reported that several of their RA subjects experienced pain during isometric contractions, but the pain was not present after the exercise session. Ekblom et al (1975a) did not assess pain during the training sessions but did note the number of complaints of pain during functional and strength testing. Their exercise group had a greater number of pain complaints during the strength post-tests than the pre-tests. In a follow-up study 6 months later (Ekblom et al 1975b), 13 of 22 patients had less pain with daily activities than they had pre-training. The number of pain complaints in the follow-up tests "seemed" to be fewer in the training group compared to the previous post-test (Ekblom et al 1975b).

Neither of these studies had compared the effects of dynamic and static exercise (training or testing) on subjective pain scores.

G. RELATIONSHIP OF PAIN AND FUNCTION SCALES

The scores on the McGill pain rating index taken pre-, mid- and post-study were compared to the exerise pain scores for periods one to three for the subjects who received training. The only significant correlation was in the third period for the Borg scale (r=.561). There were no significant correlations between scores on the functional scale and scores for exercise pain for any of the three periods.

When all subjects were taken together, significant correlations were found for the following relationships:

1. pre and post functional scores (r=.981)
2. pre and post pain rating index (r=.646)
3. post function score and post pain rating index (r=-.483)
4. pre function score and pre pain rating index (r=-.466)

It would be reasonable to assume that overall pain would affect functional ability as suggested by the negative correlation between pain rating index and function scores. Improvement in both scores could also be due to a placebo effect, ie, the patients perceive a difference because they are receiving a treatment whether it is efficacious or not. Although not statistically significant, the dip in exercise pain scores would indicate some influence of this phenomenon. However, by the end of the study the exercise pain had increased again.

The correlation of pain rating index and exercise pain in the post-test may be due partially to "getting used to" the scales. Because the experimental subjects rated pain each exercise session, by the end of the study, the pain they experienced during exercise may have had a greater influence on their answers to the PRI questionnaire. In support of this, the isokinetic group experienced less pain than the isometric group during exercise, and also showed a decrease in the post-test PRI.

H. MECHANISM OF STRENGTH CHANGES

In order to examine the possible mechanism involved in the increases in torque measurements in the patients in this study, correlation coefficients were calculated for the changes in peak torque and fibre area. The results are illustrated in table 4.17.

The correlations between the changes in fast twitch area and peak torque increase with the velocity of contraction, and are statistically significant at the three highest speeds. Using the common interpretation that the square of the correlation coefficient is the proportion of variance in Y accounted for by a linear relationship with X (Allen and Yen 1979), 91% of the variance in torque changes at 144°/sec and 192°/sec can be accounted for by changes in the size of fast twitch fibres. The remaining correlation coefficicents were not statistically significant, although the correlation between 48°/sec and fast twitch, and 0°/sec

TABLE 4.17

CORRELATION OF CHANGES IN FIBRE SIZE AND PEAK TORQUE

	VELOCITY				
FIBRE TYPE	0°/sec	48°/sec	96°/sec	144°/sec	196°/sec
FT	.267	.425	.559	.957	.953
ST	.314	.090	.187	.066	-.034

and slow twitch had probabilities of $p \leq 0.1$.

The findings indicate that improvement in torque at the higher speeds is dependent on muscle hypertrophy, and that this hypertrophy is specific to the fast twitch fibres. Changes in isometric torque and torque at 48°/sec may be more dependent on ability to recruit more muscle fibres. The joint status could be another factor affecting the isometric torque values. The isometric group had greater exercise pain than the isokinetic group. It is possible that even small changes in joint pain or swelling may influence the ability to produce muscle force during an isometric contraction. As pain during testing was not recorded, the relationship between this parameter and muscle torque cannot be determined.

The results for the RA subjects in this study are not unlike those reported in the literature for normal persons and athletes. Maximal isometric torque has been related to fibre composition in some investigations (Tesch and Karlsson 1978, Komi and Karlsson 1979, Komi et al 1977), but not by others (Thorstensson 1976, Gregor et al 1979). Komi and

Karlsson (1979) also reported that the correlation between percent FT fibres and isometric strength was lower in females than males. This could be due to the smaller size of fast twitch fibres in females (Saltin et al 1977).

Nordemar et al (1976b) reported significant positive correlations between mean area of fast twitch fibres and isometric strength although this relationship was greater following training (r=.817) than before (r=0.535). These investigators did not report on relationships between pre/post differences in these measurements.

Perhaps the pattern of muscle fibre recruitment or the force production per muscle fibre may be more or less important in different people during a maximal isometric contraction. Trained athletes may be able to recruit type II fibres to a greater extent than the untrained during two leg isometric extension (Secher et al 1976, Secher 1975, Tesch and Karlsson 1978). Milner-Brown et al (1975) reported an increase in synchronous firing of motor units during an isometric contraction after six weeks of training. On the other hand, weight lifters have larger fast twitch fibre areas than normal individuals or other athletes (Prince et al 1976, Edström and Ekblom 1972).

Gregor et al (1979) found in female athletes that the torque produced at velocities of 96°/sec and above, was related to the percentage of muscle area occupied by the fast twitch fibres. Their findings tend to support the correlations found in this study for the same speeds. They did not, however, record torque at 48°/sec.

I. CLINICAL APPLICATION OF STUDY RESULTS

The results of this study indicate that both an isometric and a high speed isokinetic training program can increase torque, work and power output of the RA muscle. The following discussion will focus on the possible benefits to the RA patient of the increase in muscle strength and consideration of the velocity of the training contraction in relation to these benefits.

Goldfuss et al (1973) reported on the effect of the degree of contraction of the quadriceps on the lateral stability of the knee. They indicated that the stronger the contraction the less movement of knee abduction and adduction occurred. The rheumatoid knee can have greater lateral instability due to involvement and stretching of the ligaments or due to apparent lengthening of the ligaments as a result of cartilage loss. Kettlekamp et al (1970) reported on the lateral movements of the knee in walking in one patient with RA and found the movement grossly abnormal in comparison to normal subjects. Therefore, the rheumatoid patient may need even greater contraction of the quadriceps than the normal subject to provide knee stability during weight bearing activities, but in fact the potential for muscle force production in RA subjects is less.

Richards (1980) recorded integrated EMG activity in the vastus medialis and the vastus lateralis of normal and RA subjects during walking. Although not statistically significant, the IEMG of the patients was generally lower, particularly in the first part of the gait cycle when knee extensor activity is required for control of the knee flexion and extension as the heel strikes the ground and weight is transferred from one leg to the other. As Richards expressed the IEMG as a percentage of the IEMG activity during a maximal quadriceps contraction, the results have even more clinical significance. The RA subjects in her study had lower maximal values of IEMG than the normal subjects.

The amount of EMG recorded is not synonymous with the force the muscle produces, but the two variables are positively correlated. Therefore, it is likely that the person with RA is producing less force in the knee extensors during gait as a result of decreased recruitment of muscle fibres and probably also due to decreased force production per motor unit.

Another factor affecting the amount of activity of the quadriceps during walking is the speed of movement. Greater forces are produced at the joints and greater muscle forces required as the gait velocity increases (Milner et al 1971). Studies on the gait of subjects with RA indicate that their gait is slower (Kettlekamp et al 1972, Richards 1980). This has been related to the pain and the need to decrease the joint forces to decrease the pain. However, it is possible that the change in speed of walking is also related to the inability of the muscle to contract with adequate force at the greater speed. PerHaps functional abilities and fibre atrophy are related in a circular fashion - pain and stiffness decrease the speed of movement which contributes to selective atrophy of the fast twitch fibres which in turn limit the ability to contract the muscle with adequate force at functional speeds.

Very little information is available on the velocity of knee movements during gait. Richards (1980) reported on a study where knee joint velocity was determined at different walking speeds. At 120 steps/min, a velocity slightly higher than that recorded for free gait (113 steps/min) by Murray (1967), knee velocity ranged from approximately 50°/sec during the stance phase to approximately 90°/sec during the swing phase. Using the normative data of Murray (1967), the author calculated velocities of the knee movement from the curve of the knee range during one complete gait cycle at 113 steps/min. With 50° and 15° of knee motion in 15% of the gait cycle for swing and stance phase respectively, the corresponding velocities were calculated to be 316°/sec and 95°/sec. Luhtanen and Komi (1980) recorded velocity of the knee during running and reported values of 286°/sec to 688°/sec during different speeds of running for track and field athletes. Although the RA subjects will not be expected to move at the speed of athletes, it would seem reasonable to expect them to run at the slower speeds when their joint status allows it.

Richards (1980) reported on the movement of the knee in one RA subject during stair climbing and rising from a chair. Visual examination of the slope of the knee movement curve in relation to time, suggested a velocity of movement during these activities similar to that for walking.

The results of Gregor et al (1979) and the correlations between changes in fibre size and torque found in this study suggest that the forces produced at velocities at and above 96°/sec are related to fast twitch fibre area. Therefore it is possible that to perform several daily functional activities at normal velocities, RA patients would benefit from a training program that would produce greater recruitment and/or hypertrophy of the type II fibres.

Both training programs employed in this study resulted in changes in torque, work and power. However, the isokinetic group more often had improvement at 96°/sec and velocities above this. There also was a greater change, although not statistically significant, in the fast twitch area in the patients in this training group. Another factor that supports the use of the isokinetic training in clinical practice is the relative lack of pain experienced during this form of exercise. If training at 180°/sec can improve torque at a functional speed (ie, at 96°/sec) with less discomfort to the patient as suggested by the present results, then there is good reason to use this method in the treatment of persons with RA.

Fatigue is a common feature of RA due chiefly to the inflammatory nature of the disease. However, if the RA patient must use a greater proportion of his maximal strength to perform daily activities, he will fatigue sooner. Improvement in muscle force at the speeds required for the individual's work or functional activities would probably have the most positive effect on the fatigue.

The fact that neither training group improved significantly in peak torque at the two highest test velocities may not be that important to the RA subject from a functional point of view. It appears that most daily activities are performed at joint velocities slower than 144° and 192°/sec. What hasn't been determined from this study is the possible benefit of using training speeds closer to the speeds of functional activities. Perhaps training at approximately 100°/sec would lead to greater torques at this speed and increased ability to perform movements such as walking and stair climbing.

If, however, the person with RA would like to get to the stage where he could exercise with jogging or cycling to improve physical fitness, then movement at the higher velocities is essential. It may be that the strength training would have to be longer in duration, more frequent, or involve a greater number of contractions than the training used in this study to obtain the changes in fast speed torques. On the other hand, it is possible that because of the muscle pathology, the improvement in fibre size or recruitment may not be great enough to account for changes in torque at the high speeds. Only by investigating different training programs will the answer to this question be known.

Although the present study has indicated that both isometric and isokinetic exercise can improve muscle strength in RA, it has not identified characteristics of patients that will respond favorably to either form of training. The subjects in this study were all in stage I or II of the disease, ie, without deformity, and yet had wide variations in their ability to improve with the training. Factors such as joint swelling or disease duration appeared to make little difference to a patient's response. However, the degree of muscle inflammation could be important and could be assessed by determining the abundance of inflammatory cells in muscle samples prepared in a similar manner to those used for staining of fibre types. Again this is an area for further investigation.

V. SUMMARY AND CONCLUSIONS

The purpose of this study was to compare the effects of isokinetic and isometric training on the strength of knee extensors and size of muscle fibres in the vastus lateralis of women with stage I or II rheumatoid arthritis. The training programs were also compared for exercise effects on knee swelling and pain.

Thirty one women with RA received seven consecutive weeks of three times weekly isometric or isokinetic training, or served as control subjects. Before and after the training, knee extension of all subjects was tested on the Cybex II isokinetic dynamometer at 0°, 48°, 96°, 144° and 192°/sec. Twenty-six subjects had pre- and post-test muscle biopsies which were prepared and stained for ATPase and then measured for FT and ST fibre size.

All subjects were evaluated on clinical parameters of disease activity and answered questionnaires on function and pain before and after the training period. The two experimental groups recorded the severity of pain they experienced during each exercise session.

The data was analysed by means of two-way ANOVAs with repeated measures on one factor. Significant differences at the probability level $p \leq 0.05$ were subjected to a Neuman-Keul post-hoc test.

Within the limitations of this study, the conclusions are:

1. Peak torque of knee extension improved in RA subjects with both isometric and isokinetic training at 0° and 48°/sec. The isokinetic group improved at 96°/sec as well. The improvement at 0°/sec was greater in the isometric group than the isokinetic group.
2. Torque at 30° increased at velocities of 0° and 48°/sec with both isometric and isokinetic training.
3. Power at 30° did not improve significantly with either isometric or isokinetic training. Changes in power were greater at 144° and 192°/sec than they were at 48° or 96°/sec with isokinetic training.
4. Work derived from the entire torque curve increased at all test velocities after isokinetic training. Improvement at 48°/sec and 96°/sec was greater than at 192°/sec. The isometric group had a statistically significant increase in the work of knee extension only at the velocity of 96°/sec.
5. Work of knee extension between 75° and 15° improved at 96° and 144°/sec with isokinetic training.
6. Power derived from the entire knee extension torque curve increased significantly at 96°, 144° and 192°/sec with isokinetic training and at 96° and 192°/sec with isometric training.
7. All measurements derived from the knee extension torque curves for any velocity were highly correlated.
8. Changes in isometric torque were not significantly correlated with changes in dynamic torque at 96°, 144°

and 192°/sec.

9. There were no statistically significant changes in the size of either FT or ST muscle fibres in the RA subjects with isokinetic or isometric training.
10. Changes in cross-sectional area of type II fibres were correlated with changes in torque at 96°, 144° and 196°/sec.
11. The group that trained isometrically experienced more pain during the exercise sessions than the group receiving isokinetic training.

Isokinetic exercise in the treatment of rheumatoid arthritis had not been evaluated prior to this study. The results from this investigation indicate that both isometric and isokinetic training programs can increase the strength of persons with rheumatoid arthritis. The isokinetic program causes less pain and leads to improvement in muscle function over several velocities of movement.

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APPENDIX A

CRITERIA FOR DIAGNOSIS AND CLASSIFICATION OF RHEUMATOID ARTHRITIS

A. CLASSICAL RHEUMATOID ARTHRITIS

This diagnosis requires seven of the following criteria. In criteria 1 through 5 the joint signs or symptoms must be continuous for at least six weeks. (Any one of the features listed under "Exclusions" will exclude a patient from this and all other categories).

1. Morning stiffness.
2. Pain on motion or tenderness in at least one joint (observed by a physician).
3. Swelling (soft tissue thickening or fluid, not bony overgrowth alone)in at least one joint (observed by a physician).
4. Swelling (observed by a physician) of at least one other joint (any interval free of joint symptoms between the two joint involvements may not be more than 3 months).
5. Symmetrical joint swelling (observed by a physician) with simultaneous involvement of the same joint both sides of the body (bilateral involvement of proximal interphalangeal, metatarsophalangeal joints is acceptable without absolute symmetry). Terminal phalangeal joint involvement will not satisfy this criterion.
6. Subcutaneous nodules (observed by a physician) over bony prominences, on extensor surfaces or in juxta-articular regions.
7. Roentgenographic changes typical of rheumatoid arthritis (which must include at least bony decalcification localized to or most marked adjacent to the involved joints and not just degenerative changes). Degenerative changes do not exclude patients from any group classified as rheumatoid arthritis.
8. Positive agglutination test-demonstration of the "rheumatoid factor" by any method which, in two laboratories, has been positive in not over 5% of normal controls.
9. Poor mucin precipitate from synovial fluid (with shreds and cloudy solution).
10. Characteristic histologic changes in synovium with three or more of the following: marked villous hypertrophy; proliferation of superficial synovial cells often with palisading; marked infiltration of chronic inflammatory cells (lymphocytes or plasma cells predominating) with tendency to form "lymphoid nodules"; deposition of compact fibrin either on surface or interstitially; foci of necrosis.
11. Characteristic histologic changes in nodules showing granulomatous foci with central zones of cell necrosis, surrounded by a palisade of proliferated macrophages, and peripheral fibrosis and chronic inflammatory cell infiltration, predominantly perivascular.

B. DEFINITE RHEUMATOID ARTHRITIS

This diagnosis requires five of the above criteria. In criteria 1 through 5 the joint signs or symptoms must be continuous for at least six weeks.

C. EXCLUSIONS

1. The typical rash of systemic lupus erythematosus (butterfly distribution, follicle plugging, and areas of atrophy).
2. High concentration of lupus erythematosus cells (four or more in two smears prepared from heparinized blood incubated not over two hours) [or other clearcut evidence of systemic lupus erythematosus.]
3. Histologic evidence of periarteritis nodosa with segmental necrosis of arteries associated with nodular leukocytic infiltration extending perivascularly and tending to include many eosinophils.
4. Weakness of neck, trunk, and pharyngeal muscles or persistent muscle swelling or dermatomyositis.
5. Definite scleroderma (not limited to the fingers).
6. A clinical picture characteristic of rheumatic fever with migratory joint involvement and evidence of endocarditis, especially if accompanied by subcutaneous nodules or erythema marginatum or chorea.
7. A clinical picture characteristic of gouty arthritis with acute attacks of swelling, redness, and pain in one or more joints, especially if relieved by colchicine.
8. Tophi
9. A clinical picture characteristic of acute infectious arthritis of bacterial or viral origin with: an acute focus of infection or in close association with a disease of known infectious origin; chills; fever; and an acute joint involvement, usually migratory initially (especially if there are organisms in the joint fluid or response to antibiotic therapy).
10. Tubercule bacilli in the joints or histological evidence of joint tuberculosis.
11. A clinical picture characteristic of Reiter's syndrome with urethritis and conjunctivitis associated with acute joint involvement, usually migratory initially.
12. A clinical picture characteristic of the shoulder-hand syndrome with unilateral involvement of shoulder and hand, with diffuse swelling of the hand followed by atrophy and contractures.
13. A clinical picture characteristic of hypertrophic osteoarthropathy with clubbing of fingers and/or hypertrophic osteoarthropathy with clubbing of fingers and/or hypertrophic periostitis along the shafts of the long bones especially if an intrapulmonary lesion (or other appropriate underlying disorder)is present.
14. A clinical picture characteristic of neuroarthropathy with condensation and destruction of bones of involved joints and with associated neurologic findings.

15. Homogentisic acid in the urine, detectable grossly with alkalinization.
16. Histologic evidence of sarcoid or positive Kveim test.
17. Multiple myeloma as evidenced by marked increase in plasma cells in the bone marrow, or Bence-Jones protein in the urine.
18. Characteristic skin lesions of erythema nodosum.
19. Leukemia or lymphoma with characteristic cells in peripheral blood, bone marrow or tissues.
20. Agammaglobulinemia.

from: Rodnan et al 1973

APPENDIX B

RADIOLOGICAL AND FUNCTIONAL CLASSIFICATION OF RHEUMATOID ARTHRITIS

1. CLASSIFICATION OF RADIOLOGICAL PROGRESSION OF RHEUMATOID ARTHRITIS

Stage I, Early
1. No destructive changes on roentgenographic examination.
2. Roentgenologic evidence of osteoporosis may be present.

Stage II, Moderate
1. Roentgenologic evidence of osteoporosis, with or without slight subchondral bone destruction; slight cartilage destruction may be present.
2. No joint deformities, although limitation of joint mobility may be present.
3. Adjacent muscle atrophy.
4. Extra-articular soft tissue lesions, such as nodules and tenovaginitis, may be present.

Stage III, Severe
1. Roentgenologic evidence of cartilage and bone destruction, in addition to osteoporosis.
2. Joint deformity, such as subluxation, ulnar deviation or hyperextension, without fibrous or bony ankylosis.
3. Extensive muscle atrophy.
4. Extra-articular soft tissue lesions, such as nodules and tenovaginitis may be present.

Stage IV, Terminal
1. Fibrous or bony ankylosis.
2. Criteria of stage III

2. CLASSIFICATION OF FUNCTIONAL CAPACITY IN RHEUMATOID ARTHRITIS

Class I - Complete functional capacity with ability to carry on all usual duties without handicaps.

Class II - Functional capacity adequate to conduct normal activities despite handicap of discomfort or limited mobility of one or more joints.

Class III - Functional capacity adequate to perform only few or none of the duties of usual occupation or of self care.

Class IV - Largely or wholly incapacitated with patient bedridden or confined to wheel-chair, permitting little or no self care.

from: Rodnan et al 1973

APPENDIX C

CYBEX CALIBRATIONS

CYBEX CALIBRATION

RECORDER SCALE	LEVER ARM inches	WEIGHT pounds	TORQUE INPUT foot-pounds	GRAPH RECORDING divisions
360	30	70.0	180	5 major
180	31	32.5	90	5 major
30	33	5.0	20	20 minor

LEVER ARM is distance from centre of Cybex input shaft to centre of T tube (lever arm length).

Procedure

1. Select recorder range scale (0-30, 0-180 or 0-360).
2. With speed selector on at 5 rpm and recorder on but no torque applied to input shaft:
    a. Select #4 position of damping control.
    b. Select slow chart speed (2mm/sec).
    c. Align stylus with baseline of char paper grid using zero adjust control.
    d. Check to see baseline does not shift when range scale is changed. Plus or minus 1 small division of change on the 30 scale is acceptable. Baseline shift can be corrected by adjusting with a small screwdriver the potentiometer behind the cap marked zero on the front vertical panel of the recorder case.
3. Attach proper amount of disc weights to T bar as per above calibration. Check accuracy of weights first as a 25 lb weight may be off as much as 0.5 lbs from its indicated value. A 2.5 lb weight may be of 0.25 lbs. Use correct weight value.
4. Dynamic calibration is done by manually lifting weighted T bar to vertical position above dynamometer, then allowing it to swing down until weights contact the floor. As weighted arm passes the horizontal, it is applying the specified torque. The graph recording will show this value as the maximum point on the curve. If this point is above or below the correct torque value, adjust the recorder and make it read the correct value by turning the appropriate (30, 180, 360) potentiometer behind the plug on the front case of the recorder using a small screwdriver. Turning the potentiometer clockwise will decrease the reading and counterclockwise will increase it.

PROCEDURE FOR CALIBRATING CYBEX DIGITAL WORK INTEGRATOR

1. Set Cybex recorder to have 0 volts on AUX OUTPUT when 0

torque or force is applied to Cybex input arm.
  a. Adjust voltage by turning potentiometer behind zero hole on front panel of recorder with small slotted screw driver.
  b. NOTE: Cybex speed selector should be ON but no torque applied to dynamometer. Set speed selector to 10 rpm.
  c. A side benefit of setting 0 volts is that the three range scales (30, 180, 360) will have baseline alignment.
  d. When using a Cybex channel selector with the recorder (so as to read out as many as four signal sources) each channel can be zeroed in a similar fashion to above via zero potentiometer on each channel of the selector.
2. Select proper machine input on integrator selector knob (Fitron, bench press, leg press, Orthotron or Cybex).
3. Turn isokinetic velocity selector knob on integrator counterclockwise to 0°/second.
4. Connect integrator to recorder with signal cable provided.
5. Turn integrator on.
6. Select X 1/10 meter scale.
7. Select hold function.
8. Adjust R8 potentiometer inside back panel of integrator such that digital readout shows + or -0.00 in hold function.
9. Turn isokinetic velocity selector knob clockwise to 200°/second.
10. Adjust R7 potentiometer inside back panel of integrator such that digital readout does not change or drift from 0.00. This cannot be done to absolute zero drift but it should not add or subtract 0.01 more frequently than every 10 seconds.
    NOTE: The system is now set up for a work integration calibration.
11. The basic procedure involves putting a known amount of work into the system and insuring that the Digital Integrator indicates the correct answer. If the digital readout is greater or less than the correct amount, R6 will be adjusted to make it read correctly. Proceed as follows:
    a. If the recorder has not been calibrated for proper torque or force readout, this must be done prior to calibrating the integrator.
    b. Assuming that the recorder is now calibrated, place the input arm of the Cybex or other machine at a horizontal position and set the velocity of that machine to zero (isometric). Apply sufficient weight to the arm of the Cybex such that a torque of 180 ft-lbs is created and so indicated on the recorder. This means that the integrator will se a torque signal of 180 ft-lbs for as long as it is switched to the integrate position.

c. Select 100°/second on isokinetic velocity knob of integrator. Thus the integrator will sum up torque under the deliberately false assumption that said torque is moving at a controlled velocity of 100°/second. Since the mechanical position of the weight on the Cybex does not really move at all, this is simply a way of providing a known torque for a measured period of time at an assumed velocity.

d. Using a good stopwatch or sweep second hand, switch the integrator to integrate for 30 seconds and then to hold to observe total work. It should read 9.42. When adjusted with R6, the unit will reproduce values within ±1% of the indicated value.

e. This simulated work value is arrived at by computation using the following formula:
Work = 2 pi x torque x angular distance traveled (radians)
Work = 2 pi x T x angular distance (degrees) x $360^{\circ -1}$
Work = 6.28 x 180 x 100°/second x 30 seconds x $360^{\circ -1}$
Work = 6.28 x 180 x 8.33
Work = 9,416 ft-lbs in 30 seconds

f. The integrator can be checked at other simulated velocities and other actual torques by varying one or both of these inputs (one simulated, one real in terms of torque applied).

APPENDIX D

QUESTIONNAIRE ON FUNCTION

DAILY LIVING SKILLS

FEEDING

(7) Are you able to feed yourself from a tray or table using ordinary utensils? Can you cut meat? can you pour liquids and open containers?
(4) If you use a spork or rocker knife or other helpful aid are you able to feed yourself in a reasonable length of time?
(2) Are you able to feed yourself with some help from another person, for example, to help you raise a cup to your mouth or to cut meat?
(0) Do you depend on another person to feed you?

DRESS UPPER BODY

(7) Are you able to get clothes out of your closets and drawers and put them on and remove them from your upper body by yourself, including bra, slip, pull-overs, and front opening shirts and blouses, as well as managing zippers, buttons, and snaps?
(4) If someone lays your clothes out for you or hands them to you, are you able to dress your upper body by yourself even if it takes a little more time, or you need some help with closures, such as buttons, zippers, snaps or hooks? Do you use aids such as reachers, dressing hooks, button hooks, or zipper pulls?
(2) Does someone help you put on your blouse or shirt or sweater because you are limited by pain, lack of strength, or limited range of motion?
(0) Do you depend on another person to dress your upper body?

DRESS LOWER BODY

(7) Are you able to put on undergarments, slacks, socks, nylons, and shoes by yourself? Can you tie shoelaces?
(4) Are you able to put on undergarments, slacks, socks, nylons, and shoes by yourself if they are laid out for you or handed to you? Do you use dressing aids such as long handled reachers? Do you avoid shoes that have laces or buckles, or do you use elastic laces or velcro shoe closures by yourself?
(2) Does someone help you to put on undergarments, slacks, nylons, or shoes?
(0) Do you depend on another person to dress your lower body?

GROOMING

(7) Are you able to comb and brush and shampoo your hair, shave, apply makeup, clean your teeth or dentures, and manage nail care by yourself without adaptations or modifications?

(4) Do you use assistive devices or adapted methods for grooming: If someone places what you need within reach are you then able to complete grooming activities unaided? Do you use long handled combs or brushes, suction brushes for cleaning nails or dentures, or manicure your nails?

(0) Do you depend on someone else entirely for your grooming needs?

CARE OF PERINEUM/CLOTHING AT TOILET

(7) Are you able to go to the bathroom by yourself including managing your clothes, wiping yourself (and placing sanitary napkins or tampons)?

(4) Are you able to manage your clothing at the toilet and wipe yourself independently although it may be difficult, or you use aids such as an extended reacher for wiping yourself or clothing aids?

(2) Does someone help you with your clothing at the toilet or assist you with wiping yourself (or in placement of sanitary napkins or tampons)?

(0) Do you depend on someone else to manage your clothes at the toilet for you or to wipe you (or to place sanitary napkins or tampons)?

WASH OR BATHE

(7) Are you able to wash and dry your entire body by yourself, including your back and feet? Are you able to turn water faucets?

(4) Do you use bathing aids such as long handled bath brushes or sponges? Are you unable to reach some parts of your body for bathing or drying thoroughly but can still manage without help?

(2) Are you able to bathe and dry most parts of your body and have someone help you with the rest?

(0) Does someone else bathe you?

VOCATIONAL

(2) Are you employed full-time in your usual occupation? Are you a full-time homemaker and require no assistance? Are you retired for other than medical

reasons?
(0) Not able to do the above.

MOBILITY

SUPINE TO SIT

(7) When you are lying on your back can you sit up without using your arms or without rolling to the side? Can you do this smoothly and easily?
(4) Do you use your arms to help you sit up or do you roll to the side before sitting up? Do you have to try several times before sitting up?
(2) Does someone help you to sit up?
(0) Are you unable to sit up?

SITTING TO STANDING

(7) Are you able to stand up from a regular chair without using your arms?
(4) Do you need to use your arms to help you stand up or do you need to try several times?
(2) Does someone need to help you stand up out of a chair?
(0) Do you depend on someone else entirely to get you out of a chair?

TRANSFER-TOILET

(7) Are you able to get on and off the toilet easily and without using your hands?
(4) Do you need to use your arms to help you get on and off the toilet or do you require assistive devices such as elevated toilet seats or grab bars?
(2) Does someone need to help you get on and off the toilet?
(0) Are you unable to use the toilet?

TRANSFER-TUB OR SHOWER

(7) Are you able to get in an out of a tub or shower safely?
(4) Can you get in and out of a tub or shower using aids such as grab bars or special seat or lift?
(2) Does someone need to help you to get in and out of the tub or shower?
(0) Are you unable to get in an out of the tub or shower?

TRANSFER-AUTO

(7) Can you get in and out of a car easily, including opening and closing the door?
(4) can you get in and out of a car by yourself if you use aids such as grab bars or if someone opens the door for you?
(2) Does someone help you get in and out of a car?
(0) Are you unable to get in and out of a car even with assistance?

WALK ON LEVEL

(7) Are you able to walk two blocks at an even pace without using a cane, crutches, walker or adapted shoes?
(4) Do you need a cane, crutches or walker to walk two blocks?
(2) Can you walk one block with assistance?
(0) Are you unable to walk one block even with assistance?

WALK OUTDOORS

(7) Are you able to walk outdoors at least two blocks without avoiding rough terrain such as grass, sand, gravel, curbs, ramps or hills?
(4) Do you try to avoid uneven terrain? Do you use a crutch or cane for safety or balance purposes only when outside?
(2) Must you use a cane or crutches to walk at least two blocks on uneven terrain?
(0) Are you unable to walk on uneven terrain?

UP AND DOWN STAIRS

(7) Can you go up and down at least five steps safely, step over step without using the hand rail or other support?
(4)
Are you able to go up and down at least five steps if you use a hand rail, cane, crutches or if you go one step at a time?
(2) Do you need someone to help you go up and down at least five steps?
(0) Are you unable to go up and down at least five steps even with help?

WHEELCHAIR/10 YARDS*

(7) Are you able to push your wheelchair without help for 10 yards? Can you turn corners, and get close to bed, table and toilet?
(4) Do you use a motorized wheelchair?
(2) Do you need someone to help you maneuver your wheelchair around corners or to help you position it?
(0) Are you unable to push your wheelchair 10 yards?

*This category not used in this study.

APPENDIX E

MCGILL PAIN RATING INDEX QUESTIONNAIRE

What does your pain feel like?

Some of the words I will read to you describe your pain. Tell me which words best describe it. Leave out any word-group that is not suitable. Use only a single word in each appropriate group--the one that applies best.

1
1 Flickering
2 Quivering
3 Pulsing
4 Throbbing
5 Beating
6 Pounding

2
1 Jumping
2 Flashing
3 Shooting

3
1 Pricking
2 Boring
3 Drilling
4 Stabbing
5 Lancinating

4
1 Sharp
2 Cutting
3 Lacerating

5
1 Pinching
2 Pressing
3 Gnawing
4 Cramping
5 Crushing

6
1 Tugging
2 Pulling
3 Wrenching

7
1 Hot
2 Burning
3 Scalding
4 Searing

8
1 Tingling
2 Itchy
3 Smarting
4 Stinging

9
1 Dull
2 Sore
3 Hurting
4 Aching
5 Heavy

10
1 Tender
2 Taut
3 Rasping
4 Splitting

11
1 Tiring
2 Exhausting

12
1 Sickening
2 Suffocating

13
1 Fearful
2 Frightful
3 Terrifying

14
1 Punishing
2 Gruelling
3 Cruel
4 Vicious
5 Killing

15
1 Wretched
2 Blinding

16
1 Annoying
2 Troublesome
3 Miserable
4 Intense
5 Unbearable

17
1 Spreading
2 Radiating
3 Penetrating
4 Piercing

18
1 Tight
2 Numb
3 Drawing
4 Squeezing
5 Tearing

19
1 Cool
2 Cold
3 Freezing

20
1 Nagging
2 Nauseating
3 Agonizing
4 Dreadful
5 Torturing

from: Melzack 1975

APPENDIX F

EXERCISE PAIN SCALES

INDICATE WITH AN X THE POINT ON THE LINE BELOW WHICH BEST DESCRIBES THE PAIN YOU EXPERIENCED DURING THIS EXERCISE SESSION.

NONE EXCRUCIATING

CIRCLE THE NUMBER THAT BEST DESCRIBES THE PAIN YOU EXPERIENCED DURING THIS EXERCISE SESSION.

0

1 very, very light

2

3 very light

4

5 rather light

6

7 moderate

8

9 rather strong

10

11 very strong

12

13 very, very strong

14

APPENDIX G

METHOD OF STAINING FOR ATPase

STAINING FOR ATPase

1. **Alkaline Preincubation:** Preincubate sections for 15 minutes in a solution of 0.1 M 2-amino-2-methyl-1-propanol containing 17 mM $CaCl_2$, adjusted to pH 10.4.

2. Rinse in two changes (one minute each, with agitation) of 0.1 M Tris HCl containing 18 mM $CaCl_2$, adjusted to pH 7.8. Drain off excess solution on blotting paper.

3. **Incubation:** Incubate sections at 37° C for 45 minutes in a 0.1 M 2-amino-2-methyl-1-propanol buffer containing 18 mM $CaCl_2$ and 2.7 mM ATP, adjusted to pH 9.4.

4. Wash sections in three 30 second changes of 0.07 M $CaCl_2$. Drain off excess solution.

5. Place in 2% cobalt chloride for three minutes.

6. Rinse in four 30 second changes of 0.1 M 2-amino-2-methyl-1-propanol buffer (adjusted to pH 9.4).

7. Place in 1% yellow ammonium sulfide for three minutes.

8. Rinse in tap water for three to five minutes.

9. Dehydrate in ascending alcohols, clear in xylene, mount in diatex

from: Guth and Samaha 1969

APPENDIX H

MEASUREMENT OF WORK AND POWER ON A DIGITIZER

MEASUREMENT OF WORK AND POWER FROM TORQUE CURVES

The area of the torque curves was measured by tracing the outline of the curves on a Hewlett Packard 9874 digitizer. The digitizer was used in conjunction with a Hewlett Packard 9825 computer with a planimetric measurement program based on the trapezoid rule.

The following are the X:Y ratios input to the computer for measurement of work and power at the five test velocities. These ratios were calculated from a recorder calibration of 1 mm = 4.88 Nm.

VELOCITY (°/sec)			
48	96	144	192
.244	.122	.082	.061

APPENDIX I

SUBJECT CONSENT FORM

CONSENT FORM

I, ______________, agree to participate in a study on exercise in rheumatoid arthritis conducted by Jean Wessel under the supervision of Dr. P. Davis and Dr. A. S. Russell. I understand that I may be in a group that receives exercise or in one that doesn't. Persons in both groups will be tested for strength and painful joints and will be asked to answer questions concerning how the disease affects their daily activities. This will be done at the beginning and at the end of the study. I understand that a muscle biopsy will be taken from my thigh at the beginning and end of the study. This involves a small cut and insertion of a biopsy needle.

I understand that if I should change my arthritis medication during the study, I will contact Jean Wessel. A change may result in my being unable to continue in the study.

I understand that if I am in the exercise group, I will be required to attend three times weekly for seven weeks for exercise on my knee.

The possible benefit I may experience from the study is an improvement in strength and function of the legs. The possible risks or hazards I may experience are discomfort or increased swelling in the knee from the exercise, and pain from the muscle biopsy. In addition, it is possible that I may not have any improvement with the exercises.

I understand that once I have agreed to participate in the study, I may still withdraw at any time, and that this withdrawal will have no bearing on my medical treatment. If I am in the non-exercise group and wish to receive an exercise program, I understand that this will be arranged once the study is over.

______________________ witness	______________________ subject
______________________ investigator	______________________ date

APPENDIX J

ANALYSIS OF VARIANCE SUMMARY TABLES

PRETEST KNEE EXTENSION PEAK TORQUE

SOURCE	SUM OF SQUARES	DF	MEAN SQUARES	F RATIO	P
BETWEEN SUBJECTS	251273.000	29			
GROUP MAIN EFFECTS	4587.508	2	2293.754	0.251	.780
SUBJECTS WITHIN GROUPS	246684.000	27	9136.441		
WITHIN SUBJECTS	254400.000	120			
ANGLE MAIN EFFECTS	213515.375	4	53378.844	155.977	.000
GROUP/ANGLE INTERACTION	3930.007	8	491.251	1.435	.190
ANGLE X SUBJECTS WITHIN	36960.000	108	342.222		

CHANGES IN KNEE EXTENSION PEAK TORQUE - STRONG AND WEAK LEGS

SOURCE	SUM OF SQUARES	DF	MEAN SQUARES	F RATIO	P
GROUP	10252.598	2	5126.297	6.045	.007
SUBJECTS WITHIN	22898.254	27	848.083		
LEG	332.854	1	332.854	1.836	.187
GROUP/LEG	139.216	2	69.608	0.384	.685
SUBJECTS WITHIN	4894.957	27	181.295		
SPEED	2263.089	4	565.772	4.510	.002
GROUP/SPEED	3522.616	8	440.327	3.510	.001
SUBJECTS WITHIN	13547.754	108	125.442		
LEG/SPEED	137.844	4	34.461	0.536	.709
GROUP/LEG/SPEED	467.078	8	58.385	0.909	.512
SUBJECTS WITHIN	6938.039	108	64.241		

CHANGES IN KNEE EXTENSION PEAK TORQUE

SOURCE	SUM OF SQUARES	DF	MEAN SQUARES	F RATIO	P
BETWEEN SUBJECTS	68002.875	29			
GROUP MAIN EFFECTS	20663.633	2	10331.816	5.893	.008
SUBJECTS WITHIN GROUPS	47339.375	27	1753.310		
WITHIN SUBJECTS	38564.438	120			
SPEED MAIN EFFECTS	4401.922	4	1100.480	4.387	.003
GROUP/SPEED INTERACTION	7071.496	8	883.937	3.524	.001
SPEED X SUBJECTS WITHIN	27091.000	108	250.843		

CHANGES IN KNEE EXTENSION TORQUE AT 30°

SOURCE	SUM OF SQUARES	DF	MEAN SQUARES	F RATIO	P
BETWEEN SUBJECTS	41880.836	29			
GROUP MAIN EFFECTS	11669.746	2	5834.871	5.215	.012
SUBJECTS WITHIN GROUPS	30211.066	27	1118.928		
WITHIN SUBJECTS	26040.000	120			
SPEED MAIN EFFECTS	885.441	4	221.360	1.037	.392
GROUP/SPEED INTERACTION	2101.127	8	262.641	1.230	.288
SPEED X SUBJECTS WITHIN	23053.453	108	213.458		

CHANGES IN KNEE EXTENSION POWER AT 30°

SOURCE	SUM OF SQUARES	DF	MEAN SQUARES	F RATIO	P
BETWEEN SUBJECTS	151268.250	29			
GROUP MAIN EFFECTS	28071.156	2	14035.578	3.076	.063
SUBJECTS WITHIN GROUPS	123197.250	27	4562.859		
WITHIN SUBJECTS	87395.000	90			
SPEED MAIN EFFECTS	16721.461	3	5573.820	7.377	.000
GROUP/SPEED INTERACTION	9469.695	6	1578.282	2.089	.063
SPEED X SUBJECTS WITHIN	61203.813	81	755.603		

CHANGES IN WORK OF KNEE EXTENSION (TOTAL)

SOURCE	SUM OF SQUARES	DF	MEAN SQUARES	F RATIO	P
BETWEEN SUBJECTS	128040.375	29			
GROUP MAIN EFFECTS	39532.145	2	19766.070	6.030	.007
SUBJECTS WITHIN GROUPS	88508.313	27	3278.085		
WITHIN SUBJECTS	24141.500	90			
SPEED MAIN EFFECTS	2535.198	3	845.066	3.373	.022
GROUP/SPEED INTERACTION	1310.118	6	218.353	0.871	.520
SPEED X SUBJECTS WITHIN	20296.188	81	250.570		

CHANGES IN WORK OF KNEE EXTENSION BETWEEN 75° AND 15°

SOURCE	SUM OF SQUARES	DF	MEAN SQUARES	F RATIO	P
BETWEEN SUBJECTS	65657.563	29			
GROUP MAIN EFFECTS	13355.148	2	6677.574	3.447	.046
SUBJECTS WITHIN GROUPS	52302.430	27	1937.127		
WITHIN SUBJECTS	9636.750	90			
SPEED MAIN EFFECTS	344.263	3	114.754	1.046	.377
GROUP/SPEED INTERACTION	402.222	6	67.037	0.611	.721
SPEED X SUBJECTS WITHIN	8890.281	81	109.757		

CHANGES IN POWER OF KNEE EXTENSION (TOTAL)

SOURCE	SUM OF SQUARES	DF	MEAN SQUARES	F RATIO	P
BETWEEN SUBJECTS	55973.844	29			
GROUP MAIN EFFECTS	13318.316	2	6659.156	4.215	.026
SUBJECTS WITHIN GROUPS	42655.527	27	1579.834		
WITHIN SUBJECTS	21217.750	90			
SPEED MAIN EFFECTS	2634.219	3	878.073	4.561	.005
GROUP/SPEED INTERACTION	2988.950	6	498.158	2.587	.024
SPEED X SUBJECTS WITHIN	15594.590	81	192.526		

CHANGES IN POWER OF KNEE EXTENSION BETWEEN 75° AND 15°

SOURCE	SUM OF SQUARES	DF	MEAN SQUARES	F RATIO	P
BETWEEN SUBJECTS	237289.250	29			
GROUP MAIN EFFECTS	50441.727	2	25220.863	3.644	.040
SUBJECTS WITHIN GROUPS	186847.625	27	6920.281		
WITHIN SUBJECTS	87506.750	90			
GROUP/SPEED INTERACTION	12891.613	3	4297.203	5.331	.002
SPEED X SUBJECTS WITHIN	65289.125	81	806.039	1.928	.086

CHANGES IN KNEE EXTENSION ISOMETRIC TORQUE

SOURCE	SUM OF SQUARES	DF	MEAN SQUARES	F RATIO	P
BETWEEN SUBJECTS	69916.250	29			
GROUP MAIN EFFECTS	27514.813	2	13757.406	8.760	.001
SUBJECTS WITHIN GROUPS	42401.500	27	1570.426		
WITHIN SUBJECTS	23555.375	60			
ANGLE MAIN EFFECTS	1961.329	2	980.664	2.754	.073
GROUP/ANGLE INTERACTION	2366.329	4	591.641	1.662	.172
ANGLE X SUBJECTS WITHIN	19227.500	54	356.065		